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1c685 U.S. PTO

# UTILITY PATENT APPLICATION TRANSMITTAL

Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No. 2355.11109

First Named Inventor or Application Identifier

YUKIO SAKAGAWA, ET AL.

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## APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

## ADDRESS TO:

Assistant Commissioner for Patents  
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Washington, DC 20231

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1. ☒ Fee Transmittal Form  
(Submit an original, and a duplicate for fee processing)

2. ☒ Specification Total Pages **59**

3. ☒ Drawing(s) (35 USC 113) Total Sheets **36**

4. ☒ Oath or Declaration Total Pages **2**

- a. ☒ Newly executed (original or copy)  
b. ☐ Unexecuted for information purposes  
c. ☐ Copy from a prior application (37 CFR 1.63(d))  
(for continuation/divisional with Box 17 completed)  
[Note Box 5 below]

i. ☐ **DELETION OF INVENTOR(S)**  
Signed Statement attached deleting  
inventor(s) named in the prior application, see  
37 CFR 1.63(d)(2) and 1.33(b).

5. ☐ Incorporation By Reference (useable if Box 4c is checked)  
The entire disclosure of the prior application, from which a copy of  
the oath or declaration is supplied under Box 4c, is considered as  
being part of the disclosure of the accompanying application and is  
hereby incorporated by reference therein.

6. ☐ Microfiche Computer Program (Appendix)

7. Nucleotide and/or Amino Acid Sequence Submission  
(if applicable, all necessary)

- a. ☐ Computer Readable Copy  
b. ☐ Paper Copy (identical to computer copy)  
c. ☐ Statement verifying identity of above copies

## ACCOMPANYING APPLICATION PARTS

8. ☒ Assignment Papers (cover sheet & document(s))  
9. ☐ 37 CFR 3.73(b) Statement (when there is an assignee) ☐ Power of Attorney  
10. ☐ English Translation Document (if applicable)  
11. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations  
12. ☐ Preliminary Amendment  
13. ☒ Return Receipt Postcard (MPEP 503)  
(Should be specifically itemized)  
14. ☐ Small Entity ☐ Statement filed in prior application  
Statement(s) Status still proper and desired  
15. ☒ Certified Copy of Priority Document(s)  
(if foreign priority is claimed)  
16. ☒ Other: Claim to priority

17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No. \_\_\_\_\_

## 18. CORRESPONDENCE ADDRESS

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CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
	TOTAL CLAIMS (37 CFR 1.16(c))	74-20 =	54	X \$ 18.00 =	\$ 972.00
	INDEPENDENT CLAIMS (37 cfr 1.16(b))	18-3 =	15	X \$ 78.00 =	\$1170.00
	MULTIPLE DEPENDENT CLAIMS (if applicable) (37 CFR 1.16(d))			\$ 260.00 =	\$ 0.00
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	Reduction by 50% for filing by small entity (Note 37 CFR 1.9, 1.27, 1.28).				
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19. Small entity status

- a. ☐ A Small entity statement is enclosed
- b. ☐ A small entity statement was filed in the prior nonprovisional application and such status is still proper and desired.
- c. ☐ Is no longer claimed.


20. ☒ A check in the amount of \$ 2832.00 to cover the filing fee is enclosed.

21. ☒ A check in the amount of \$ 40.00 to cover the recordal fee is enclosed.

22. The Commissioner is hereby authorized to credit overpayments or charge the following fees to Deposit Account No. 06-1205:

- a. ☒ Fees required under 37 CFR 1.16.
- b. ☐ Fees required under 37 CFR 1.17.
- c. ☐ Fees required under 37 CFR 1.18.

**SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED**

NAME	Brian L. Klock - Reg. No. 36,570
SIGNATURE	
DATE	February 25, 2000

BLK\cmv

TITLE OF THE INVENTION  
IMAGE PROCESSING METHOD AND APPARATUS

FIELD OF THE INVENTION

5           The present invention relates to an image processing apparatus and method for shading or shadowing a virtual object using a virtual light source upon expressing a virtual space on the basis of photo image data.

10           The present invention also relates to an image processing apparatus and method for changing a real illumination condition in real time and generating a mixed reality image in accordance with the changed condition.

15

BACKGROUND OF THE INVENTION

Many schemes for describing a virtual space based not on a three-dimensional geometric shape but on a photo image have been proposed. Such schemes are  
20   called Image Based Rendering (to be abbreviated as IBR hereinafter), and can express a virtual space with high reality that cannot be obtained by a scheme based on a three-dimensional geometric shape.

Attempts to describe a virtual space on the basis  
25   of the ray space theory as one IBR scheme have been proposed. See, for example, "Implementation of Virtual

Environment by Mixing CG model and Ray Space Data",  
IEICE Journal D-11, Vol. J80-D-11 No. 11, pp. 3048  
- 3057, November 1997, or "Mutual Conversion between  
Hologram and Ray Space Aiming at 3D Integrated Image  
5 Communication", 3D Image Conference, and the like.

The ray space theory will be explained below.

As shown in Fig. 1, a coordinate system  $O-X-Y-Z$   
is defined in a real space. A light ray that passes  
through a reference plane  $P$  ( $Z = z$ ) perpendicular to  
10 the  $Z$ -axis is defined by a position  $(x, y)$  where the  
light ray crosses  $P$ , and variables  $\theta$  and  $\phi$  that  
indicate the direction of the light ray. More  
specifically, a single light ray is uniquely defined by  
five variables  $(x, y, z, \theta, \phi)$ . If a function that  
15 represents the light intensity of this light ray is  
defined as  $f$ , light ray group data in this space can be  
expressed by  $f(x, y, z, \theta, \phi)$ . This five-dimensional  
space is called a "ray space".

If the reference plane  $P$  is set at  $z = 0$ , and  
20 disparity information of a light ray in the vertical  
direction, i.e., the degree of freedom in the  $\phi$   
direction is omitted, the degree of freedom of the  
light ray can be reduced to two dimensions. This  $x$ - $\theta$   
two-dimensional space is a partial space of the ray  
25 space. As shown in Fig. 3, if  $u = \tan\theta$ , a light ray  
(Fig. 2) which passes through a point  $(X, Z)$  in the

real space is mapped onto a line in the x-u space,  
which line is given by:

$$X = x + uZ \quad (1)$$

Image sensing by a camera corresponds to  
5 registering in an imaging plane the rays that passes  
through the lens focal point of the camera, and the  
intensity and color of the ray is represented as an  
image. In other words, the set of light rays that  
passes through one point in the real space, i.e., the  
10 focal point position, corresponds to the set of  
captured pixels. In this, since the degree of freedom  
in the  $\phi$  direction is omitted, and the behavior of a  
light ray is examined in only the X-Z plane, only  
pixels on a line segment that intersects a plane  
15 perpendicular to the Y-axis need be considered. In  
this manner, by sensing an image, light rays that pass  
through one point can be collected, and data on a  
single line segment in the x-u space can be captured by  
single image sensing.

20 When an image is sensed a large number of times  
by changing the viewpoint position, light ray groups  
which pass through a large number of points can be  
captured. When the real space is sensed using N  
cameras, as shown in Fig. 4, data on a line given by:

$$25 \quad x + Z_n u = X_n \quad (2)$$

can be input in correspondence with a focal point position  $(X_n, Z_n)$  of the  $n$ -th camera ( $n = 1, 2, \dots, N$ ), as shown in Fig. 5. In this way, when an image is sensed from a sufficiently large number of view points, 5 the  $x$ - $u$  space can be densely filled with data.

Conversely, an image observed from a new arbitrary viewpoint position can be generated (Fig. 7) from the data of the  $x$ - $u$  space (Fig. 6). As shown in Fig. 7, an image observed from a new viewpoint position 10  $E(X, Z)$  indicated by an eye mark can be generated by reading out data on a line given by equation (1) from the  $x$ - $u$  space.

In the mixed reality space that takes a photo image into a virtual space, real and virtual spaces are 15 mixed. For this reason, image processes which are easy to implement in a real or virtual space alone may become hard to implement.

Image processes using photo image data do not excel in addition of shades and generation of a shadow 20 by means of virtual illumination. This is because although shades or shadow change in accordance with the three-dimensional pattern of an object, it is hard to reconstruct shades or shadow since photo image data does not have any information pertaining to the 25 geometric shape of the object. That is, a technique for rendering a virtual object on the basis of space

data including geometric shape information, rendering shades to be added to that object or rendering a shadow formed by the object is known to those skilled in an image processing field based on geometric shape information (e.g., computer graphics (to be abbreviated as CG hereinafter)), but is unknown in an image processing field using a photo image such as a ray space or the like.

One difficulty in generation of a mixed reality space involves changing a real illumination condition and mixing a virtual image with a real space in real time in correspondence with the change in illumination condition.

Conventionally, the brightness of a real space is measured by a batch method, and the detected illumination condition is reflected in the mixed reality space.

#### SUMMARY OF THE INVENTION

The present invention has been proposed to solve the conventional problems, and has as its object to provide an image processing method and apparatus suitable for recording space data, which is suitable for generating shades of a virtual object from space data based on a photo image.

It is another object of the present invention to provide an image processing method and apparatus for generating shades of a virtual object from space data based on a photo image at high speed.

5           It is still another object of the present invention to provide an image processing method and apparatus capable of appropriately generating shades even when the position or condition of a virtual light source is arbitrarily changed.

10           It is still another object of the present invention to provide an image processing method and apparatus capable of generating shades for a virtual object described in space data based on a photo image.

            It is still another object of the present  
15   invention to provide an image processing method and apparatus capable of pasting a shadow image to a virtual object image from space data based on a photo image.

            It is still another object of the present  
20   invention to provide an image processing method and apparatus suitable for real-time processes for directly generating a shadow image from space data, and pasting the shadow image in a virtual space.

            It is still another object of the present  
25   invention to provide a mixed reality presentation apparatus for constructing a mixed reality space in



response to a change in real illumination condition in real time.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10 The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

15 Fig. 1 is a view for explaining the principle for generating ray space data;

Fig. 2 is a view for explaining data in a real space;

20 Fig. 3 is a view showing the space shown in Fig. 2, which is expressed by ray space data;

Fig. 4 is a view for explaining the principle of generating real space data when there are a plurality of cameras;

25 Fig. 5 is a view for explaining the principle of generating ray space data when there are a plurality of cameras;

Fig. 6 is a view for explaining the principle of generating ray space data ( $x + Z_u = X$ ) at an arbitrary viewpoint position from ray space data when there are a plurality of cameras;

5        Fig. 7 is a view for explaining the principle of reconstructing a real space from an arbitrary viewpoint in Fig. 6;

Fig. 8 is a block diagram for explaining the arrangement of an image processing apparatus according  
10    to the first embodiment of the present invention;

Fig. 9 is a view for explaining storage of ray space data in the first embodiment;

Fig. 10 is a view for explaining a scheme for obtaining a photo image with shades of an object at  
15    each of a plurality of different camera viewpoints when the object is illuminated from a plurality of different illumination positions;

Fig. 11 is a chart for explaining the process for generating ray space data of a photo image with shades  
20    of an object;

Fig. 12 is a view for explaining generation of shades of a virtual object illuminated by virtual illuminations placed at  $L_1$  and  $L_2$  when viewed from virtual viewpoint position  $i$ ;

25        Fig. 13 is a view for explaining shades added to the virtual object shown in Fig. 12;

Fig. 14 is a view for explaining a scheme for extracting ray space data RS corresponding to viewpoint position  $i$  and illumination positions  $L_1$  and  $L_2$  from data stored in a disk;

5        Fig. 15 is a flow chart showing the control sequence until a photo image with shades of an object is captured and is converted into ray space data;

10       Fig. 16 is a table which stores illumination conditions set upon obtaining ray space data shown in Fig. 15;

Fig. 17 is a flow chart showing the control sequence for generating an image with shades of a virtual object when an arbitrary virtual illumination is set;

15       Fig. 18 is a flow chart for explaining a rendering routine in Fig. 17;

Fig. 19 is a flow chart for explaining a restart routine in Fig. 17;

20       Fig. 20 is a view for explaining the principle of controlling the pixel value in accordance with the illumination position with respect to an object;

Fig. 21 is a view for explaining the principle of generating a silhouette serving as a source of a shadow image of an arbitrary object;

25       Fig. 22 is a view showing an example of the silhouette extracted by the principle of Fig. 21;

Fig. 23 is a view for explaining a change in silhouette obtained by Fig. 22 with changing virtual illumination position (to be lower);

Fig. 24 is a view for explaining a change in  
5 silhouette obtained by Fig. 22 with changing virtual illumination position (to be higher);

Fig. 25 is a view for explaining the principle of generating a mapping plane in the first embodiment;

Fig. 26 is a flow chart showing the control  
10 sequence for generating a shadow image beforehand;

Fig. 27 is a flow chart showing the control sequence for pasting a shadow image generated beforehand to a virtual object;

Fig. 28 is a view for explaining a method for  
15 generation of a simple shadow image;

Fig. 29 is a block diagram for explaining the arrangement of a mixed reality presentation apparatus according to the second embodiment of the present invention;

Fig. 30 is a view for explaining the arrangement  
20 of an illumination unit used in the apparatus of the second embodiment;

Fig. 31 is a block diagram functionally showing operations in principal parts of the mixed reality  
25 presentation apparatus;

Fig. 32 is a view for explaining a GUI used to change illumination conditions;

Fig. 33 is a flow chart showing the control sequence of a mixed reality space management module;

5 Fig. 34 is a flow chart showing the control sequence of a CG image generation module; and

Fig. 35 is a view showing the arrangement of a modification of an illumination device.

Fig. 36 shows a table stored in a memory, in  
10 which illumination positions (Ln) and ray space data RS(Ln) are registered.

Fig. 37 shows a table stored in a memory, in which illumination positions (Ln) and shadow data SHADOW(Ln) are registered.

15 Figs 38A to 38C show change of a displayed object in accordance with operation of virtual illumination.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention  
20 will now be described in detail in accordance with the accompanying drawings.

##### [First Embodiment]

An image processing apparatus and method according to the first embodiment of the present  
25 invention will be described in detail below with

reference to the accompanying drawings. The image processing apparatus and method have a function of rendering shades to be added to a virtual object by a virtual illumination from ray space data, and rendering  
5 a shadow by the virtual illumination.

Fig. 8 shows the arrangement of an image processing system of this embodiment. The hardware arrangement shown in Fig. 8 is that of a normal workstation. More specifically, the hardware  
10 arrangement itself is the same as that of a normal workstation.

This system presents a virtual space to the user on a CRT 23. The user can freely walk through that virtual space or can manipulate (move, rotate, enlarge,  
15 or the like) an object in the virtual space by operating a mouse 28. More specifically, an object in the real space is converted into ray space data on the basis of a photo image, and the converted data is stored in advance in a disk 25. When the viewpoint  
20 position moves as the user walks through, a ray space data object image at the moved viewpoint position is generated, as has been explained with reference to Fig. 7. This image is mapped on a transparent plate laid out in the virtual space by a texture mapper 24,  
25 and the entire virtual space including the mapped image is rendered and displayed on the CRT 23. The texture

mapper 24 also maps the texture of a shadow to a transparent plate laid out on the bottom portion of the object.

Fig. 9 explains the recording method of ray space data stored in the disk 25 in this system. That is, as has been explained in Figs. 1 to 7, ray space data expressed by a single line in an  $(X, u)$  space corresponds to a photo image that was converted in this line image.

Referring to Fig. 8, reference numeral 29 denotes a color camera for obtaining a photo image. The camera 29 is mounted on a moving mechanism 30, and a CPU 20 drives the moving mechanism 30 in accordance with a control program (to be described later) to move the position of the camera 29. The CPU 20 can detect the moved position of the camera, i.e., the moved viewpoint position (including posture), via the moving mechanism 30. Reference numeral 32 denotes an illumination light source. This light source is moved to an arbitrary position via a moving mechanism 31. The moved position is detected by the CPU 20.

The camera 29 and, especially, the illumination light source 32 are movable to sense shades generated by illuminations (real illuminations) at a plurality of known positions. This system generates ray space data with shades in advance on the basis of real shade

images. Also, this system holds silhouette images of an object viewed from the light source positions as a shadow image database.

#### <Generation of Shades by Virtual Illumination>

5            Fig. 10 explains the principle of capturing shade data. Referring to Fig. 10, reference numeral 100 denotes a real object, which is a circular cone 100 in this example, for the sake of simplicity. Also, in Fig. 10, reference numerals 101 and 102 denote image  
10    sensing routes, along which a plurality of image sensing positions are designated. In the example shown in Fig. 10, the route 101 vertically makes a round of the circular cone 100, and the route 102 horizontally makes a round of the circular cone 100. For example,  
15    when the circular cone 100 is sensed at 36 points of viewpoint positions in  $10^\circ$  increments along the route 101 (one round =  $360^\circ$ ), 36 images of the circular cone 100 can be obtained, and these 36 color images are those of the object 100 with shades. The sensed images  
20    are converted into ray space data by the aforementioned method, and are stored in the disk 25.

            Referring to Fig. 10, reference numerals 200 and 201 denote moving routes of the illumination light source 32. The moving routes 200 and 201 have, e.g.,  
25    semi-circular arcuated shapes, and are perpendicular to each other. That is, the routes 200 and 201



respectively have  $180^\circ$  moving ranges. Assuming that the light source 32 moves in  $10^\circ$  increments, 18 points of illumination positions for each of the routes 200 and 201 (a total of 36 points) can be obtained.

5           As will be described later, the number of illumination positions influences the precision of the shapes of shades and shadow. Hence, the  $10^\circ$  increment width along each of the horizontal and vertical image sensing routes is merely an example, and the increment  
10          width can be arbitrarily increased/decreased as needed.

          In this example, ray space data are respectively generated at 36 points of illumination positions. Each ray space data are generated from 36 images. If RS represents one object, the object RS can be expressed  
15       by  $RS(L)$  since it has an argument L of an illumination position. Fig. 11 illustrates a state wherein a real image  $RI_i(L)$  (i is the viewpoint position along the route 101 or 102) obtained by sensing the real object 100 illuminated from the illumination position L by the  
20       camera 29 is temporarily stored in the disk 25 and is converted into a ray space data object  $RS(L)$ , and the converted object is stored.

          Fig. 12 explains a scheme for generating shades upon rendering a virtual image 100' of the object 100  
25       at a certain viewpoint position in a virtual space with a plurality of virtual illuminations. In the example

shown in Fig. 12, three virtual illuminations ( $L_1$ ,  $L_2$ ,  $L_3$ ) are set in the virtual space, and the virtual illuminations ( $L_1$ ,  $L_2$ ) are ON, and the virtual illumination ( $L_3$ ) is OFF. Then, light shades must be  
5 formed on regions 300 and 301 of the surface of the circular cone 100 as a virtual object, and a dense shade on a region 302. When the virtual object 100 formed with such shades is viewed from virtual viewpoint position  $i$ , a virtual image shown in Fig. 13  
10 should be obtained by rendering. In order to implement such rendering, a ray space data object image  $RS_i(L_1)$  generated at viewpoint position  $i$  by setting a light at the illumination position  $L_1$  and a ray space data object image  $RS_i(L_2)$  generated at viewpoint position  $i$   
15 by setting a light at the illumination position  $L_2$  can be mixed, as shown in Fig. 14.

Fig. 15 is a flow chart for explaining the storage sequence of ray space data according to the first embodiment. An image of a real object  
20 illuminated by an illumination  $L_n$  is captured at camera viewpoint position  $i$  (step S10), and the captured image is saved (step S12). This operation is repeated for all a plurality of predetermined viewpoint positions  $i$  (steps S14 and S16). The plurality of image data  
25 obtained in step S10-S16 are converted into ray space data  $RS(L_n)$  of the illumination  $L_n$  (step S18), and the

converted data are saved in the disk 25 (step S20).  
The aforementioned process is repeated for all the  
illuminations (steps S22 and S24). In this manner, the  
camera 29 is directed to the real object at each of a  
5 plurality of camera viewpoint positions  $i$ , the real  
object is illuminated from each of a plurality of  
illumination positions  $L_n$  to capture images of the real  
object, the captured image data are converted into ray  
space data RS in units of illumination positions  $L_n$ ,  
10 and the converted data are saved in the disk 25 as  
shown in Fig. 36.

As explained later, appropriate ray space data  
can be obtained by searching the table shown in Fig. 36  
based on relative position between the object and the  
15 virtual illumination (step S62 of Fig. 18).

Fig. 16 shows various illumination conditions of  
the illumination device at the individual illumination  
positions. These illumination conditions were recorded  
upon storing ray space data of a real image. When an  
20 application program of this image processing system  
implements walkthrough in a virtual space, it virtually  
turns on/off the respective illuminations (virtual  
illuminations) in accordance with its specifications or  
by receiving a user instruction upon rendering a  
25 virtual object in the virtual space. That is, as has  
been explained above in relation to Figs. 12 and 13, an

image of a virtual object with shades is rendered considering the sum of the contributions of all ON illuminations.

Fig. 17 shows the control sequence for rendering  
5 an image by that application program.

In step S30, viewpoint position  $i$  to be rendered is determined. It is checked in step S32 if rendering of ray space data objects pre-stored in correspondence with viewpoint position  $i$  of interest is complete. If  
10 rendering is not complete, the flow advances to step S34, the table shown in Fig. 16 is searched for virtual illuminations the user (or the application program) wants to turn on. Processes in steps S38 and S40 are done for a ray space object  $RS(L_{ON})$  corresponding to a  
15 designated ON virtual illumination. Note that  $L_{ON}$  is the number of a designated ON virtual illumination. Fig. 18 shows the rendering process in step S38 in detail.

If  $L_n$  represents the number of the ON  
20 illumination, steps S60 to S64 process an object  $RS(L_n)$ . That is, the relative position of the object with respect to the illumination  $L_n$  is computed in step S60, and object data is acquired by searching the table shown in Fig. 36 in accordance with that relative  
25 position in step S62. In step S64, an image of the object  $RS(L_n)$  is generated in consideration of

illuminance of the illumination  $L_n$ . For each of R, G, and B values which do not consider any illumination, the pixel value of is changed larger with increasing illuminance value and decreasing distance to the  
5 illumination. That is, as shown in Fig. 20, considering the illuminance ( $R_0$ ) and position (i.e., distance  $D_0$ ) of a real illumination, with respect to a virtual illumination (illuminance  $R_x$ , distance  $D_x$ ) located in the same direction as the real illumination,  
10 a pixel value  $P_x$  of a virtual image is given by:

$$P_x = f(P, D_x, D_0, R_x, R_0)$$

where P is the pixel value of a real image, and f is a predetermined function.

In this manner, rendering of an object is  
15 completed.

Referring back to Fig. 17, the next ON illumination is referred to in step S40, and the flow returns to step S36 to repeat processes in step S38 → step S40.

20 Upon completion of the process in step S38 for all ON virtual illuminations, the flow advances to step S42 to compute the sum of pixel values of that pixel computed for the respective virtual illuminations. In this case, the sum of pixel values can be obtained by  
25 simply adding the pixel values of the respective generated images at the corresponding pixel position.

It is checked in step S44 if the sum of pixel values computed in step S42 overflows, i.e., exceeds the gamut of the display device (CRT 23). If YES in step S44, a restart process is done in step S46. In the restart  
5 process, the illuminance of the virtual illumination is decreased not to cause any overflow, and rendering is redone. Fig. 19 shows details of the restart process.

In step S66, objects are marked to indicate overflow. In step S68, the set illuminance values of  
10 all the virtual illuminations (see the table in Fig. 16) are decreased. In step S70, a virtual environment is rendered again.

On the other hand, if it is determined in step S44 that no overflow is detected, the next object is  
15 referred to in step S50, and the flow returns to step S32. If YES is determined in step S32, ray space data have been processed for all pixels for one frame, and as a result, a virtual image under a condition that two virtual illuminations are ON (Fig. 12) is generated, as  
20 shown in, e.g., Fig. 13.

#### <Effect of Shade Addition>

As described above, according to shade generation of this embodiment, shades from an illumination at a desired position can be appropriately generated even  
25 for a virtual object expressed by IBR data (having no

geometric shape information) of the ray space theory or the like.

<Addition of Shadow by Virtual Illumination>

The image processing apparatus of this embodiment  
5 also has a function of adding a shadow by a virtual illumination in addition to addition of shades by the virtual illumination. The shape of a shadow is dominated by the geometric shape of an object and the shape of a plane (to be referred to as a "mapping  
10 plane" hereinafter) on which the shadow is projected. However, since an IBR image such as ray space data or the like does not have any geometric shape for an object, it is conventionally difficult to implement processes pertaining to a shadow, as described early.  
15 The image processing apparatus of this embodiment generates a shadow image in advance like in shading. The mapping plane is generated using a so-called "bounding box" known to those who are skilled in the CG art.

20 Figs. 21 and 22 illustrate the principle of a scheme for generating shadow data of the circular cone 100 as an example of a real object.

More specifically, when an illumination 32 illuminates a real circular cone 100 from the position  
25 in Fig. 21, the camera 29 is set at a position substantially matching that (including a posture) of

the illumination 32 to sense an image of the object 100 illuminated by the illumination 32. This image 120 has a shape, as shown in, e.g., Fig. 22, and its silhouette 121 should have a shape approximate to a shadow  
5 generated when the object 100 is illuminated by the illumination 32. In other words, when shades are generated, an image is sensed by the camera to record photo images of the object added with shades in the form of ray space data in advance. But upon generating  
10 a shadow, an image of the object is sensed to obtain a shadow image.

The silhouette 121 serves as a basis of a shadow image, and will be simply referred to as an "edge shape" hereinafter. A shadow formed by a virtual  
15 illumination (i.e., a virtual shadow) can be obtained by computing the coordinate transform of the silhouette to have the viewpoint position of the virtual illumination as a coordinate axis, i.e., the affine transform. For example, when the angle of elevation of  
20 the virtual illumination is low, an elongated shadow should be generated, as shown in Fig. 23; when the angle of elevation is high, a shadow with a short length should be generated, as shown in Fig. 24.

The shape of a shadow is influenced by the shape  
25 of the mapping plane in addition to the silhouette shape. When the mapping plane is determined, the



shadow shape is obtained by projecting the silhouette onto the mapping plane. This projected shape is expressed by an affine transform.

The principle of generating the mapping plane  
5 will be explained below.

A shadow of an object has a shape corresponding to the shape of said object. That is, a shadow is formed within a range corresponding to the shape of an object. A feature of this embodiment is to limit the  
10 shape (i.e., range) of the mapping plane to that of the mapping plane of the bounding box of an object (virtual object).

For example, when virtual images of two animal toys 301 having complicated geometric shapes in  
15 practice are present, as shown in Fig. 25, a bounding box that includes all spatial spreads of these virtual images is obtained. This box is normally set to have a rectangular parallelopiped shape, and is a box 300 in the example shown in Fig. 25. A projected shape 302 of  
20 this box is a rectangle, as shown in Fig. 25. This projected shape 302 serves as the mapping plane.

Fig. 26 shows the control sequence for obtaining the edge shape.

In step S100, the camera 29 and illumination  
25 device 32 are set at an arbitrary position L. In step S102, a real object is illuminated by the illumination

32 at this position L to capture its image. In step  
S104, a silhouette is acquired from that image. In  
step S106, pixel values in that silhouette are set to  
be black. Also, the transparency is set at a  
5 predetermined value (which does not indicate 100%  
transparency but allows to see through the surface of  
the virtual object).

A process in step S108 is selectively done. That  
is, if the image sensing plane (the camera  
10 position/posture) is not parallel to the projective  
plane (illumination position/posture), a re-projection  
process of a shadow image is required. However, in the  
example shown in Fig. 21 since these planes are not  
parallel to each other and the angle these planes make  
15 is small, errors are expected to be small, and little  
difference is observed if such re-projection process is  
not done. When a silhouette is obtained not from a  
real object but from a virtual object, the perspective  
viewing volume can be set so that the rendering plane  
20 matches the plane of a shadow image.

A blur process in step S108 considers the fact  
that an actual shadow is blurred at its edge portion.  
That is, by adding the blur process, a shadow image can  
look more natural. Furthermore, by increasing the blur  
25 value for a shadow projected at a position farther from  
the object, the natural feel can be further enhanced.

When this blur process is done for an silhouette image generated from an image of a virtual object, it can be implemented using a jittered viewing volume used upon rendering an image using a depth-of-field effect.

5           In step S110, the obtained shadow image data is saved. In step S112, the next image sensing position (illumination position)  $L+1$  is selected, and the processes in steps S100 to S112 are repeated until the processes are done for all the illumination positions.

10           Note that the shadow data is saved in step S110 to be indexed by the relative position value between the illumination and object as shown in Fig. 37.

          In this manner, silhouettes obtained upon illuminating an object from a plurality of illumination  
15 positions can be prepared as shadow images.

Fig. 27 explains the sequence for rendering a shadow in detail.

          More specifically, ray space data of a virtual object for which a shadow is to be generated is read  
20 out from the memory in step S120.

          In step S122, all virtual illuminations that may generate shadows are detected. Steps S126 to S134 implement a rendering process of a shadow image formed by an ON illumination of those detected virtual  
25 illuminations. More specifically, one ON illumination  $L$  is found in step S126. In step S128, the shape of

the mapping plane is computed. The shape of the mapping plane can be computed if the geometric shape of the bounding box of a virtual object and the relative position of a light source are given, as described

5 above. The geometric shape of the shadow mapping plane can be set so that an arbitrary element in its bounding box has a shadow projected onto that mapping plane.

Note that the bounding box used to determine the mapping plane can be used to create a simple shadow  
10 image in some cases. For example, when light reflected by a ceiling or external light serves as a light source, a very simple shadow image like an ellipse 305 that inscribes the bounding box can be used, as shown in Fig. 28.

15 In step S130, a shadow image is rendered in correspondence with the relative position of the object with respect to the illumination L. As has been described above in step S110, the shadow image is indexed by the value of the relative position of the  
20 real object (virtual object) with respect to the illumination L (see Fig. 37). Hence, an image corresponding to shadow data can be read out from the memory using the relative position. If required, re-projection and shadow image blur processes are  
25 executed. In step S132, the generated shadow image is

mapped on the mapping plane. This mapping is implemented using texture mapping (24 in Fig. 8).

In step S134, the flow returns to step S124 to consider another illumination. If another ON  
5 illumination is available, in other words, if shadows formed by a plurality of illuminations may exist, the shadow images generated by the aforementioned scheme are mixed by known CG rendering (in consideration of semi-transparency of an image).

10 <Effect of Shadow Generation>

According to shadow generation of the above embodiment, a shadow formed by an illumination at a desired position can be appropriately generated even for a virtual object expressed by IBR data (having no  
15 geometric shape information) of the ray space theory or the like.

Various modifications of the present invention can be made.

In the above embodiment, ray space data are  
20 obtained by computations, but a RAM or ROM that stores them as a table may be used.

The display device is not limited to the CRT. For example, a lenticular or HMD type display device may be used.

25 The above embodiment has exemplified a method of holding in advance images sensed from all possible

illumination positions. This is because ray space data objects used have only horizontal disparities but ignore vertical disparities. If a ray space data object can be generated in also consideration of the  
5 vertical disparity, an image of an object viewed from a given position of an illumination is generated using that ray space data object, and a silhouette can be rendered. In the ray space theory, not only the horizontal disparity but also vertical disparity can be  
10 provided, and such process can be implemented by expanding the aforementioned ray space data process pertaining to the horizontal disparity in the vertical direction. Hence, even when shadow data are not sensed in advance, the silhouette of an image viewed from an  
15 illumination position can be generated in real time using ray space data objects, and a shadow can be expressed by re-projecting the generated image.

When a plurality of illuminations are used, a silhouette image is generated at each illumination  
20 position, and shadows can be mixed by the scheme described in the above embodiment.

To restate, according to the present invention, shades can be appropriately added to a virtual object defined by space data based on a photo image.

Also, according to the present invention, a shadow can be appropriately mapped on a virtual object defined by space data based on a photo image.

[Second Embodiment]

5           A mixed reality presentation apparatus according to the second embodiment of the present invention will be described in detail below with reference to the accompanying drawings.

Fig. 29 is a block diagram showing the overall  
10 arrangement of a mixed reality presentation system of this embodiment.

Referring to Fig. 29, reference numeral 106  
denotes a sensor for measuring the viewpoint position and line-of-sight direction of the user. This sensor  
15 may be a magnetic or optical sensor provided outside user's body or a sensor attached to an HMD (Head Mounted Display) the user wears. The measured viewpoint position and posture are sent to an image generation module 103. The image generation module 103  
20 generates a CG image in consideration of the viewpoint position and line of sight of the user.

On the other hand, an image sensing device 105  
uses a video camera or the like for sensing an image of a real space. The image sensing device 105 is  
25 preferably attached to the head of the user when the viewpoint position and line-of-sight direction of the

user change. An image input module 104 converts an image sensed by the image sensing device 105 into an object, also generates a depth value of a given object in that image, and passes them on to an image mixing  
5 module 102.

The image mixing module 102 mixes the CG image generated by the image generation module 103 with the video image from the image input module 104. In this mixing, as is well known, occlusion is determined by  
10 comparing the depth values of the CG image and video image, and a mask corresponding to a portion to be hidden of a behind object is generated, thus mixing the video and CG images.

Note that the image generation module 103  
15 receives information that pertains to illumination conditions from a mixed reality space management module 108. That is, the image generation module 103 generates a CG with shades in accordance with the illumination conditions.

20 In this embodiment, a real illumination device 107 is used to illuminate an object. The management module 108 can change the illuminance, illumination direction, and the like of the illumination device. The management module 108 converts changed conditions  
25 of the illumination device 107 into predetermined



parameter values, and passes them on to the image generation module 103.

Fig. 30 shows an example of the illumination device 107. This illumination device has a light control unit 206, which is pivotally supported by a boom 205 via a joint (not shown). The boom 205 is fixed to a support shaft 202 via a joint 204. The support shaft 202 is pivotally fixed on a rotary stage 203, which is slidably placed on a slide table 201. Hence, the light control unit can slide, pan, tilt, and rotate. In addition, since the joints, rotary stage, and the like are driven by motors, they can be controlled by a signal from the management unit 108. Furthermore, the amount of light can be controlled by controlling the voltage/current to be applied to the light control unit. Also, since each motor, joint, slide table, and light control unit respectively have a rotary encoder, goniometer, linear distance sensor, and illuminance sensor, their position/posture information can be acquired.

Fig. 31 explains the relationship among the illumination device 107, management module 108, and image mixing module 103.

A GUI 120 is a graphic user interface which is displayed on a display device by the management module to change illumination conditions. Fig. 32 shows an

example of the GUI. Referring to Fig. 32, arrows are control buttons which can be changed by, e.g., a mouse. For example, when the user wants to slide the illumination unit horizontally, he or she clicks one of the right and left arrows with the mouse, and moves the desired arrow in a desired direction. When the user wants to adjust angle, he or she selects the arrow of a portion to be changed by clicking the mouse and rotates it using, e.g., a joystick. Using this GUI, the angles of the respective portions of the illumination unit shown in Fig. 30, brightness and color of illumination, and the like can be changed using a keyboard, joystick, or the like. Note that in the GUI, the arrow of a portion to be changed may be selected by clicking the mouse and the angle may be set by dragging the mouse in place of the joystick.

The illumination conditions set by the user via this GUI are sent to a controller 107b in the illumination device 107. The controller 107b converts the illumination conditions into drive amounts of the motors and the like of the illumination device 107, and outputs them. In this manner, the illumination device 107 is set at illuminance and the like set by the user via the GUI.

On the other hand, the illumination conditions set via the GUI are converted into illumination

condition parameters, e.g., angle, specular, ambient,  
position, diffusion, and the like defined by a space  
language used in the generation module 103. Note that  
these parameter values are determined in advance by  
5 experiments under various illumination conditions. The  
image generation module 103 sets the received parameter  
values in a rendering routine.

Fig. 33 shows the control sequence of the mixed  
reality space management module 108, and Fig. 34 shows  
10 the control sequence of the image generation module 103.  
The mixed reality space management module 108 and image  
generation module 103 are program modules and  
communicate with each other via an API (Application  
Program Interface) of a predetermined protocol. More  
15 specifically, the management module 108 monitors in  
step S102 if the user has changed illumination  
conditions using the GUI. If YES in step S102, the  
module 108 computes various controlled variables for  
the illumination unit in step S104, and send them to  
20 the controller 107b of the illumination device 107 in  
step S106. The module 108 generates illumination  
parameters such as angle in step S108, and the like and  
send them to the image generation module 103 via an API  
in step S110. In step S112, the module 108 generates  
25 an event and informs the module 103 of the event.

In the flow chart shown in Fig. 34, the image generation module 103 waits for generation of an event (step S202). If an event is generated, the module 103 confirms in step S204 if the event is an illumination condition change event, and receives illumination parameters via an API in step S206. In step S208, the module 103 replaces parameters in the rendering routine by the received parameters. In step S210, the module 103 renders a CG image in accordance with the received parameters. The rendered CG image has shades or the like, which have been changed in accordance with the changed illumination conditions.

The states of such changes of a CG image are shown in Figs. 38A to 38C. An illumination device 3802 has light source 3803, control buttons 3804 for adjusting illumination brightness and manipulator 3805 for turning the illumination device in horizontal direction around the axis 3806. The illumination (light source) is at a position "n". Accordingly, an object image 3801 is rendered based on ray space data  $RS(Ln)$ .

Various modifications of this embodiment may be made within the scope of the present invention.

Fig. 35 explains a modification of an illumination unit 107a. In this modification, the light control unit 206 is supported by a tilt unit 301,

which is axially supported to be free to tilt. The tilt unit 301 is vertically movable. A support shaft 304 is connected to a motor 303 and can be rotated to pan the light control unit. The support shaft 304 is  
5 parallelly movable along a slide table 302. The slide table 302 is movable in a direction perpendicular to the moving direction of the shaft 304.

In the above embodiment, the GUI is used to change illumination conditions. Instead, hardware  
10 devices such as a volume, slide switch, joystick, and the like may be used. When such hardware devices are used, output signals from these devices must be sent to the apparatus having the management module.

In the apparatus of the above embodiment, the  
15 illumination conditions are changed under the control of a computer. The present invention is not limited to such specific control. For example, the present invention can be applied when the illumination conditions are manually changed. On the other hand,  
20 condition change values on the GUI 120 may be read by the controller 107b in a software manner. In this modification, the need for the rotary encoder in the above embodiment can be obviated. In order to detect changes in illumination conditions, an illuminance  
25 sensor, a sensor for detecting illumination direction,

and the like are provided, and these sensor outputs are supplied to the management module.

In the above embodiment, illumination program parameters are pre-stored in a predetermined memory 121, but may be computed in real time on the basis of the detected illuminance, illumination direction, and the like. For this purpose, conversion formulas for deriving parameter values from the detection values of the illumination conditions may be pre-stored in the memory, and parameters may be computed using these conversion formulas in real time.

To recapitulate, according to the present invention, the illumination conditions of a virtual image can be acquired in real time in correspondence with changes in real illumination. For this reason, deviation of image quality between real and virtual images due to structural differences of the illumination conditions can be minimized.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the claims.

WHAT IS CLAIMED IS:

1. An image processing method for describing a real image as a virtual object using space data formed based on a photo image of the real object, and generating a  
5 virtual image of the virtual object using the space data, comprising the steps of:

capturing the photo image of the real object from a real camera viewpoint position while illuminating the real object by an illumination light source placed at a  
10 real illumination position;

converting the photo image into space data in the form of an object; and

storing the space data in a memory together with various illumination conditions at the real  
15 illumination position to allow a search at a later time.

2. The method according to claim 1, wherein the illumination position of the illumination light source is set at a plurality of different positions, and position information and an illumination condition at  
20 each illumination position are stored in the memory together with corresponding space data.

3. The method according to claim 1, wherein the camera viewpoint position is set at a plurality of different positions, and space data obtained at each  
25 viewpoint position is stored together with the viewpoint position information.

4. The method according to claim 1, wherein the space data is ray space theory data.

5. The method according to claim 1, wherein the illumination condition is varied in a plurality of ways per illumination position, and space data corresponding to the individual illumination conditions are stored in the memory.

6. An image processing method for describing a real image as a virtual object using space data formed based on a photo image of the real object, and generating a virtual image of the virtual object using the space data, comprising the steps of:

storing space data generated from a photo image together with a real camera viewpoint position, and an illumination position and illumination condition of a real illumination light source;

generating coordinates of a virtual image of an object at a user viewpoint position on the basis of the real camera viewpoint position and the space data; and

correcting pixel values of the virtual image on the basis of the real illumination position and real illumination condition of the real illumination light source, and a virtual illumination position and virtual illumination condition set for a virtual illumination light source.



7. The method according to claim 6, wherein the illumination position of the real illumination light source is set at a plurality of different positions, and position information and an illumination condition  
5 at each illumination position are stored in the memory together with corresponding space data.

8. The method according to claim 6, wherein the real camera viewpoint position is set at a plurality of different positions, and space data obtained at each  
10 viewpoint position is stored together with the viewpoint position information.

9. The method according to claim 6, wherein the space data is ray space theory data.

10. The method according to claim 6, further  
15 comprising the step of changing and setting an illumination condition of the virtual illumination light source to be an arbitrary value, and wherein the correction step includes the step of correcting the pixel values in accordance with the changed  
20 illumination condition.

11. The method according to claim 6, wherein when a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective virtual  
25 illumination light sources are added for one pixel position to obtain a final pixel value.

12. The method according to claim 6, wherein when some of a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective ON

5 virtual illumination light sources are added for one pixel position to obtain a final pixel value.

13. The method according to claim 6, further comprising the steps of:

determining if the corrected pixel value  
10 saturates; and

virtually changing illumination conditions of some or all of the virtual light sources in a direction to decrease luminance or illuminance of an illumination when the pixel value saturates, and

15 wherein the correction step is executed again in accordance with the changed illumination condition.

14. The method according to claim 6, wherein the illumination condition includes information indicating whether or not an illumination is turned on.

20 15. The method according to claim 6, wherein the illumination condition includes illuminance or luminance.

16. The method according to claim 6, wherein the illumination condition includes a relative position  
25 between the virtual light source and object.

17. The method according to claim 6, wherein the illumination condition includes color of illumination.

18. An image processing apparatus for describing a real image as a virtual object using space data formed  
5 based on a photo image of the real object, and generating a virtual image of the virtual object using the space data, comprising:

means for capturing the photo image of the real object from a real camera viewpoint position while  
10 illuminating the real object by an illumination light source placed at a real illumination position;

conversion means for converting the photo image into space data in the form of an object for each pixel; and

15 means for storing the space data in a memory together with various illumination conditions at the real illumination position to allow a search at a later time.

19. The apparatus according to claim 18, wherein the  
20 illumination position of the illumination light source is set at a plurality of different positions, and position information and an illumination condition at each illumination position are stored in the memory together with corresponding space data.

25 20. The apparatus according to claim 18, wherein the camera viewpoint position is set at a plurality of

different positions, and space data obtained at each viewpoint position is stored together with the viewpoint position information.

21. The apparatus according to claim 18, wherein the  
5 space data is ray space theory data.

22. The apparatus according to claim 18, wherein the illumination condition is varied in a plurality of ways per illumination position, and space data corresponding to the individual illumination conditions are stored in  
10 the memory.

23. An image processing apparatus for describing a real image as a virtual object using space data formed based on a photo image of the real object, and generating a virtual image of the virtual object using  
15 the space data, comprising:

means for storing space data in the form of an object for each pixel of a photo image together with a real camera viewpoint position, and an illumination position and illumination condition of a real  
20 illumination light source;

generation means for generating coordinates of a virtual image of an object at a user viewpoint position on the basis of the real camera viewpoint position and the space data; and

25 correction means for correcting pixel values of the virtual image on the basis of the real illumination

position and real illumination condition of the real illumination light source, and a virtual illumination position and virtual illumination condition set for a virtual illumination light source.

5 24. The apparatus according to claim 23, wherein the illumination position of the real illumination light source is set at a plurality of different positions, and position information and an illumination condition at each illumination position are stored in the memory  
10 together with corresponding space data.

25. The apparatus according to claim 23, wherein the real camera viewpoint position is set at a plurality of different positions, and space data obtained at each viewpoint position is stored together with the  
15 viewpoint position information.

26. The apparatus according to claim 23, wherein the space data is ray space theory data.

27. The apparatus according to claim 23, further comprising means for changing and setting an  
20 illumination condition of the virtual illumination light source to be arbitrary values, and wherein said correction means corrects the pixel values in accordance with the changed illumination condition.

28. The apparatus according to claim 23, wherein when  
25 a plurality of virtual light sources are ON at the same time, a plurality of correction results which are

corrected in accordance with the respective virtual illumination light sources are added for one pixel position to obtain a final pixel value.

29. The apparatus according to claim 23, wherein when  
5 some of a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective ON virtual illumination light sources are added for one pixel position to obtain a final pixel value.

10 30. The apparatus according to claim 23, further comprising:

means for determining if the corrected pixel value saturates; and

means for virtually changing illumination  
15 conditions of some or all of the virtual light sources in a direction to decrease luminance or illuminance of an illumination when the pixel value saturates, and

wherein said correction means is executed again in accordance with the changed illumination condition.

20 31. The apparatus according to claim 23, wherein the illumination condition includes information indicating whether or not an illumination is turned on.

32. The apparatus according to claim 23, wherein the illumination condition includes illuminance or  
25 luminance.

33. The apparatus according to claim 23, wherein the illumination condition includes a relative position between the virtual light source and object.

34. The apparatus according to claim 23, wherein the  
5 illumination condition includes color of illumination.

35. An image processing method for generating a shadow image of a virtual object itself in a virtual space, comprising the steps of:

sensing an image of a real object by a camera  
10 while illuminating the real object corresponding to the virtual object from a light source at a predetermined illumination position;

extracting a silhouette of the real object from the image of the real object;

15 adding preferred image information as a shadow to pixels in the silhouette; and

storing the silhouette image together with position information of the light source, the silhouette image being able to be found by search and  
20 retrieved at a later time.

36. The method according to claim 35, wherein the preferred image information includes a predetermined black pixel value and a predetermined transparency value.

25 37. The method according to claim 35, wherein the silhouette image undergoes a blur process.

38. The method according to claim 37, wherein the degree of blur is changed in correspondence with distance from the virtual object to a virtual light source.

5 39. The method according to claim 35, wherein a viewpoint position of the camera matches the position of the illumination light source.

40. An image processing method for generating a shadow image of a virtual object itself in a virtual  
10 space, comprising the steps of:

storing space data of the virtual object, a shadow image of a real object corresponding to the virtual object, and a position of an illumination light source upon forming the shadow image in a predetermined  
15 memory;

reading out the shadow image from the memory in accordance with a position of a virtual illumination, and a relative position of the virtual object; and

mapping the readout shadow image on a  
20 predetermined mapping plane.

41. The method according to claim 40, wherein the mapping plane is determined on the basis of a bounding box of the virtual object.

42. The method according to claim 40, further  
25 comprising the step of changing and setting an illumination condition of the virtual illumination



light source to be an arbitrary value, and wherein the correction step includes the step of correcting the pixel values in accordance with the changed illumination condition.

5 43. The method according to claim 40, wherein when a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective virtual illumination light sources are added for one pixel  
10 position to obtain a final pixel value.

44. The method according to claim 40, wherein when some of a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective ON  
15 virtual illumination light sources are added for one pixel position to obtain a final pixel value.

45. The method according to claim 40, wherein when the illumination is located at a high-level position, a mapping plane with a simple shape is generated.

20 46. An image processing apparatus for generating a shadow image of a virtual object itself in a virtual space, comprising:

means for sensing an image of a real object by a camera while illuminating the real object corresponding  
25 to the virtual object from a light source at a predetermined illumination position;

means for extracting a silhouette of the real object from the image of the real object;

means for adding preferred image information as a shadow to pixels in the silhouette; and

5 means for storing the edge image together with position information of the light source, the silhouette image being able to be found by search and retrieved at a later time.

47. The apparatus according to claim 46, wherein the  
10 preferred image information includes a predetermined black pixel value and a predetermined transparency value.

48. The apparatus according to claim 46, wherein when  
the viewpoint position of the camera is different from  
15 the position of the light source, the silhouette image is corrected by re-projecting the silhouette image to have the position of the light source as a viewpoint position.

49. The apparatus according to claim 46, further  
20 comprising means for performing a blur process of the silhouette image.

50. The apparatus according to claim 49, wherein the  
degree of blur is changed in correspondence with  
distance from the virtual object to a virtual light  
25 source.

51. The apparatus according to claim 46, wherein a viewpoint position of the camera matches the position of the illumination light source.

52. An image processing apparatus for generating a  
5 shadow image of a virtual object itself in a virtual space, comprising the steps of:

means for storing space data of the virtual object, a shadow image of a real object corresponding to the virtual object, and a position of an  
10 illumination light source upon forming the shadow image in a predetermined memory;

means for reading out the shadow image from the memory in accordance with a position of a virtual illumination, and a relative position of the virtual  
15 object; and

means for mapping the readout shadow image on a predetermined mapping plane.

53. The apparatus according to claim 52, wherein the mapping plane is determined on the basis of a bounding  
20 box of the virtual object.

54. The apparatus according to claim 52, further comprising means for changing and setting an illumination condition of the virtual illumination light source to be an arbitrary value, and wherein said  
25 correction means corrects the pixel values in accordance with the changed illumination condition.

55. The apparatus according to claim 52, wherein when a plurality of virtual light sources are ON at the same time, a plurality of correction results which are corrected in accordance with the respective virtual  
5 illumination light sources are added for one pixel position to obtain a final pixel value.

56. The apparatus according to claim 52, wherein when some of a plurality of virtual light sources are ON at the same time, a plurality of correction results which  
10 are corrected in accordance with the respective ON virtual illumination light sources are added for one pixel position to obtain a final pixel value.

57. The apparatus according to claim 52, wherein when the illumination is located at a high-level position, a  
15 mapping plane with a simple shape is generated.

58. An image processing method for generating a shadow image of a virtual object itself in a virtual space, comprising the steps of:

extracting a silhouette of the virtual object  
20 viewed from a predetermined illumination position on the basis of space data which expresses the virtual object;

adding preferred image information as a shadow to pixels in the silhouette; and

25 mapping the silhouette image on a predetermined mapping plane.

59. An image processing apparatus for generating a shadow image of a virtual object itself in a virtual space, comprising:

means for extracting a silhouette of the virtual  
5 object viewed from a predetermined illumination  
position on the basis of space data which expresses the  
virtual object;

means for adding preferred image information as a  
shadow to pixels in the silhouette; and

10 means for mapping the silhouette image on a  
predetermined mapping plane.

60. An image processing apparatus for mixing a  
virtual space with a real space illuminated by a real  
illumination device, and presenting the mixed space,  
15 comprising:

change means for changing an illumination  
condition of the illumination device;

first setting means for setting an illumination  
program parameter value corresponding to a value of the  
20 changed illumination condition;

rendering means for rendering a virtual image  
using a predetermined illumination condition program  
parameter, and mixing the virtual image with the real  
space; and

25 second setting means for setting, in a rendering  
routine of the virtual image of said rendering means,

the illumination condition program parameter set by  
said setting means in correspondence with the  
illumination condition changed by said change means.

61. The apparatus according to claim 60, wherein the  
5 illumination condition includes one of illuminance,  
color, and an illumination direction.

62. The apparatus according to claim 60, wherein said  
change means comprises GUI means operated by a user to  
display control buttons for graphically changing  
10 illuminance, color, and an illumination direction of  
the illumination device on a display screen.

63. The apparatus according to claim 60, wherein said  
change means comprises GUI means operated by a user,  
and said GUI means displays an image that simplifies  
15 the illumination device and allows the user to instruct  
to change a given illumination condition by designating  
a portion to be adjusted in the image using a pointing  
device.

64. The apparatus according to claim 60, wherein said  
20 first setting means includes means for reading out a  
parameter pre-stored in a predetermined memory.

65. An image processing method for mixing a virtual  
space with a real space illuminated by a real  
illumination device, comprising:

25 the step of changing an illumination condition of  
the illumination device;

the first setting step of setting an illumination program parameter value corresponding to a value of the changed illumination condition;

the step of rendering a virtual image using a  
5 predetermined illumination condition program parameter, and mixing the virtual image with the real space; and

the second setting step of setting, in a rendering routine of the virtual image, the illumination condition program parameter set in  
10 correspondence with the illumination condition changed in the change step.

66. The method according to claim 65, wherein the first setting step includes the step of reading out a parameter pre-stored in a predetermined memory.

15 67. The method according to claim 65, wherein the change step includes the step of displaying a GUI operated by a user to display control buttons for graphically changing illuminance, color, and an illumination direction of the illumination device on a  
20 display screen.

68. The method according to claim 65, wherein the change step includes the step of displaying a GUI operated by a user, and the GUI displays an image that simplifies the illumination device and allows the user  
25 to instruct to change a given illumination condition by

designating a portion to be adjusted in the image using a pointing device.

69. A storage medium that stores a control program for making a computer execute an image process for  
5 describing a real image as a virtual object using space data formed based on a photo image of the real object, and generating a virtual image of the virtual object using the space data, said control program including:

a code of the capture step of capturing the photo  
10 image of the real object from a real camera viewpoint position while illuminating the real object by an illumination light source placed at a real illumination position;

a code of the conversion step of converting the  
15 photo image into space data in the form of an object; and

a code of the storage step of storing the space data in a memory to allow a search together with various illumination conditions at the real  
20 illumination position.

70. A storage medium that stores a control program for making a computer execute an image process for describing a real image as a virtual object using space data formed based on a photo image of the real object,  
25 and generating a virtual image of the virtual object using the space data, said control program including:



a code of the storage step of storing space data generated from a photo image together with a real camera viewpoint position, and an illumination position and illumination condition of a real illumination light source;

a code of the generation step of generating coordinates of a virtual image of an object at a user viewpoint position on the basis of the real camera viewpoint position and the space data; and

10 a code of the correction step of correcting pixel values of the virtual image on the basis of the real illumination position and real illumination condition of the real illumination light source, and a virtual illumination position and virtual illumination

15 condition set for a virtual illumination light source.

71. A storage medium that stores a control program for making a computer execute an image process for generating a shadow image of a virtual object itself in a virtual space, said control program including:

20 a code of the image sensing step of sensing an image of a real object by a camera while illuminating the real object corresponding to the virtual object from a light source at a predetermined illumination position;

a code of the extraction step of extracting a silhouette of the real object from the image of the real object;

a code of the addition step of adding preferred  
5 image information as a shadow to pixels in the silhouette; and

a code of the storage step of storing the silhouette image together with position information of the light source, the silhouette image being able to be  
10 found by search and retrieved at a later time.

72. A storage medium that stores a control program for making a computer execute an image process for generating a shadow image of a virtual object itself in a virtual space, said control program including:

15 a code of the storage step of storing space data of the virtual object, a shadow image of a real object corresponding to the virtual object, and a position of an illumination light source upon forming the shadow image in a predetermined memory;

20 a code of the read-out step of reading out the shadow image from the memory in accordance with a position of a virtual illumination, and a relative position of the virtual object; and

a code of the mapping step of mapping the readout  
25 shadow image on a predetermined mapping plane.

73. A storage medium that stores a control program for making a computer execute an image process for generating a shadow image of a virtual object itself in a virtual space, said control program including:

- 5 a code of the extraction step of extracting a silhouette of the virtual object viewed from a predetermined illumination position on the basis of space data which expresses the virtual object;
- a code of the addition step of adding preferred
- 10 image information as a shadow to pixels in the silhouette; and
- a code of the mapping step of mapping the silhouette image on a predetermined mapping plane.

74. A storage medium that stores a control program for making a computer execute an image process for generating a shadow image of a virtual object itself in a virtual space, said control program including:

- a code of the step of changing an illumination condition of the illumination device;
- 20 a code of the first setting step of setting an illumination program parameter value corresponding to a value of the changed illumination condition;
- a code of the step of rendering a virtual image using a predetermined illumination condition program
- 25 parameter, and mixing the virtual image with the real space; and

a code of the second setting step of setting, in  
a rendering routine of the virtual image, the  
illumination condition program parameter set in  
correspondence with the illumination condition changed  
5 in the change step.

# ABSTRACT OF THE DISCLOSURE

There is provided an image processing apparatus for describing a real image as a virtual object using space data formed based on a photo image of the real object, and generating a virtual image of the virtual object using the space data. The image processing apparatus captures the photo image of the real object from a real camera viewpoint position while illuminating the real object by an illumination light source placed at a real illumination position. The captured photo image is converted into space data in the form of an object for each pixel, and the space data is stored in a memory together with various illumination conditions at the real illumination position to allow a search at a later time.

FIG. 1

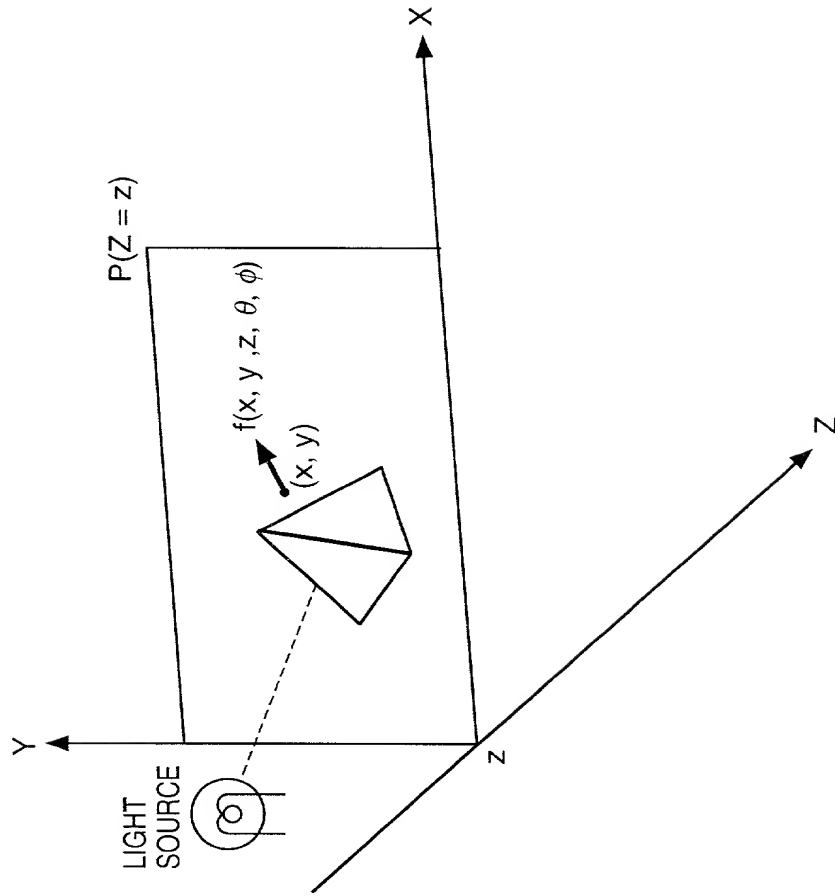
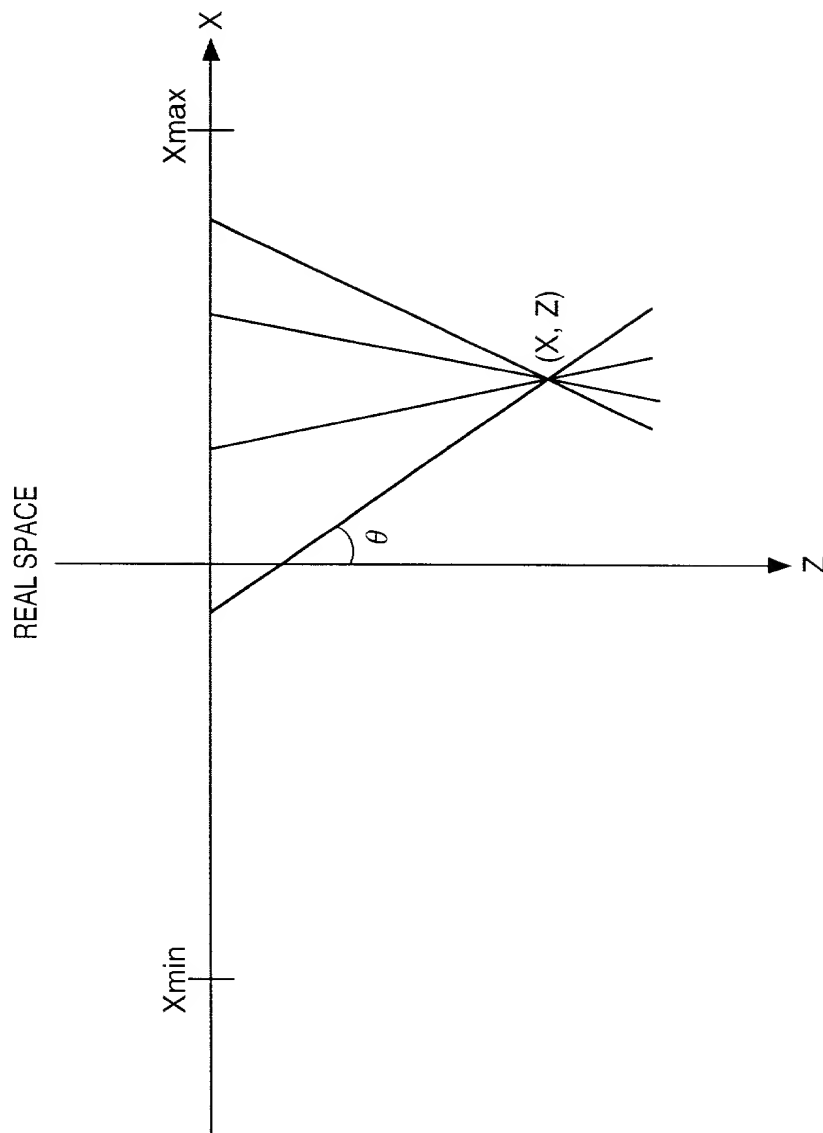


FIG. 2



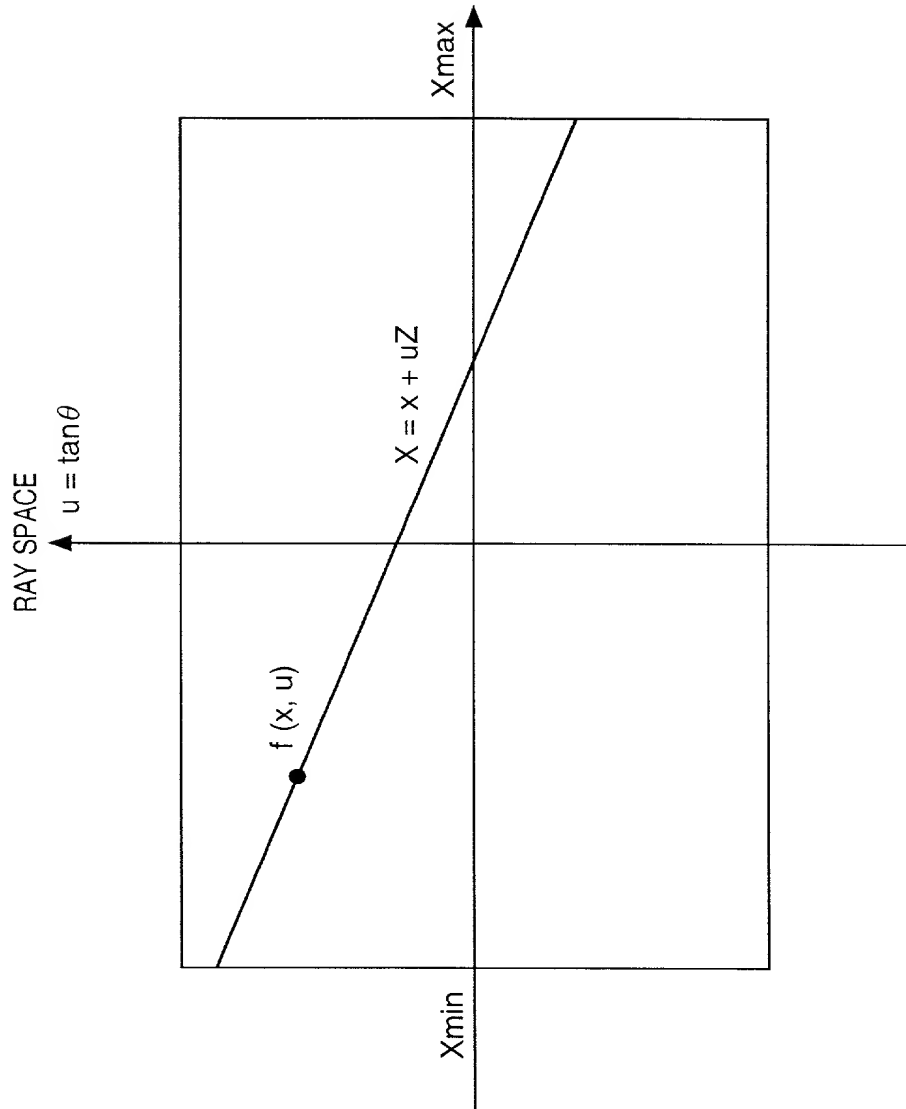
**FIG. 3**



FIG. 4

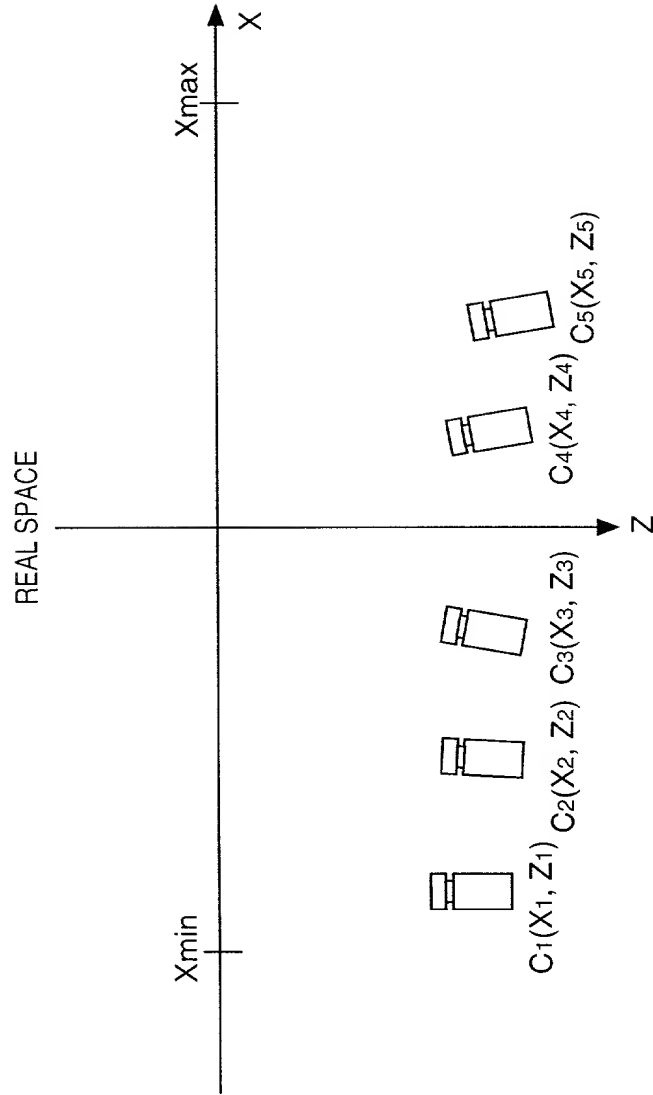


FIG. 5

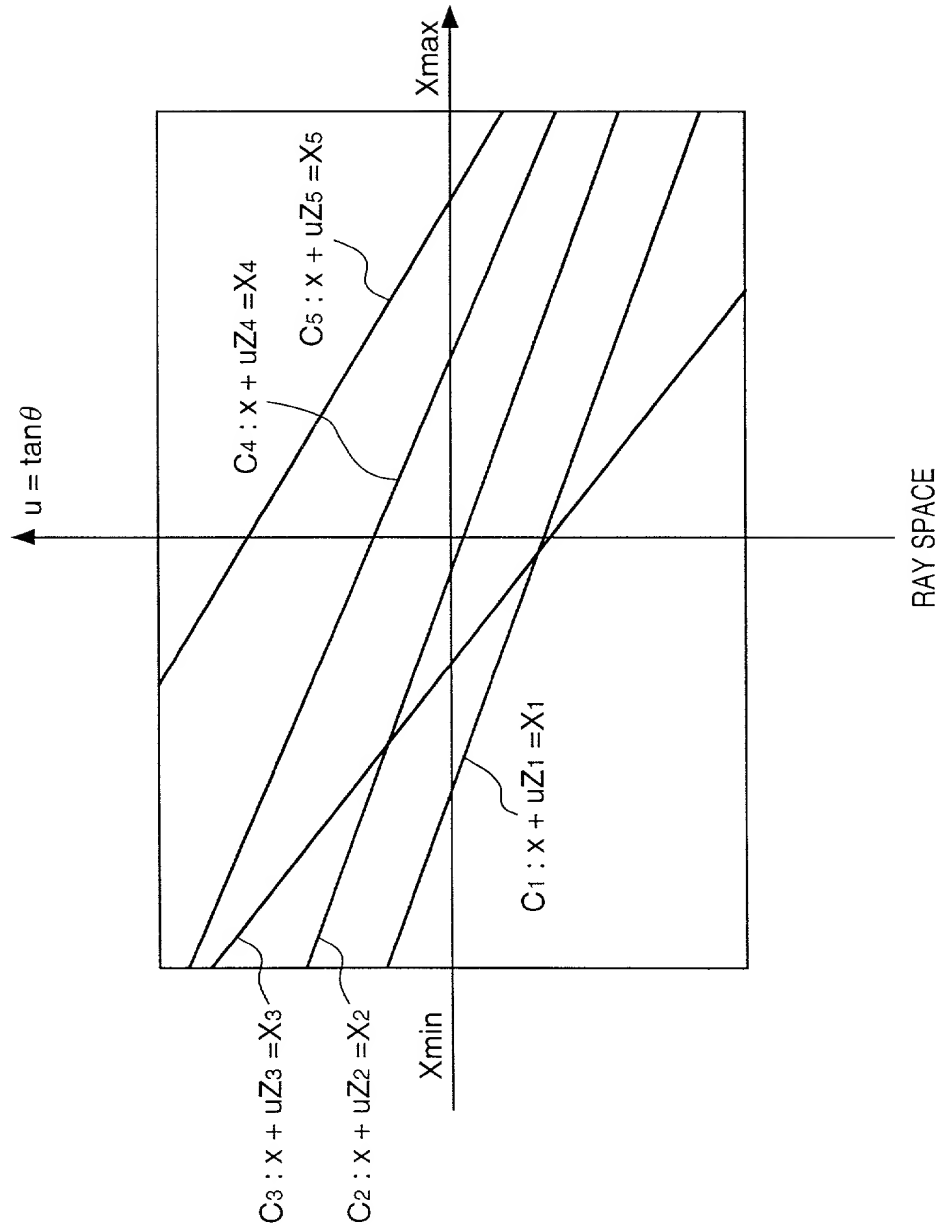


FIG. 6

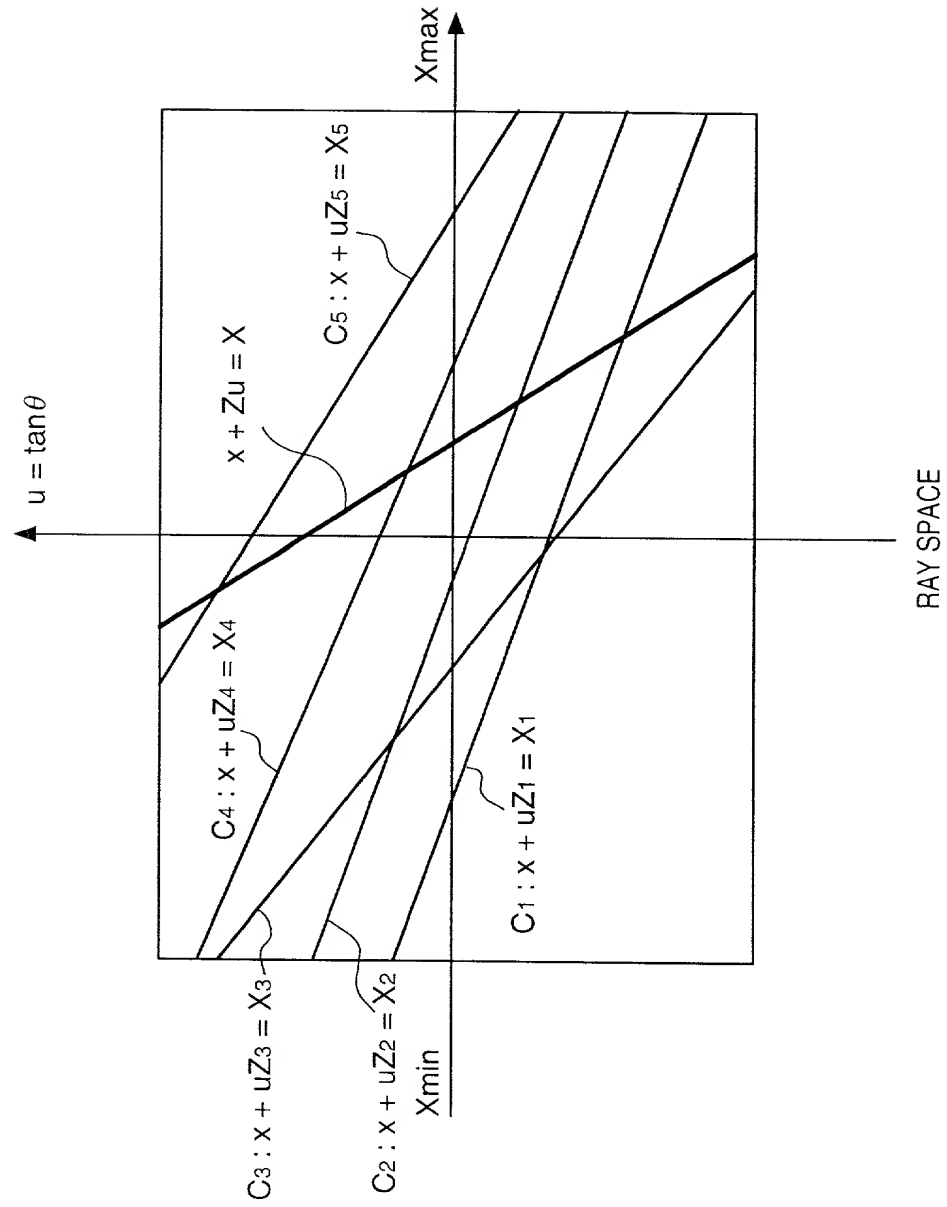


FIG. 7

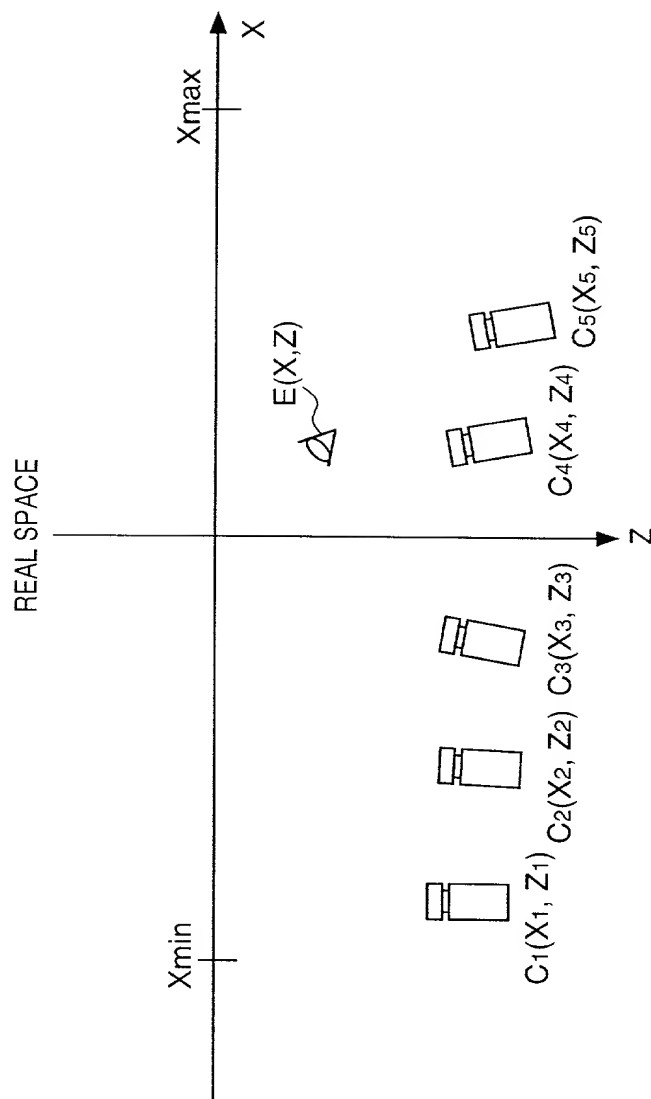


FIG. 8

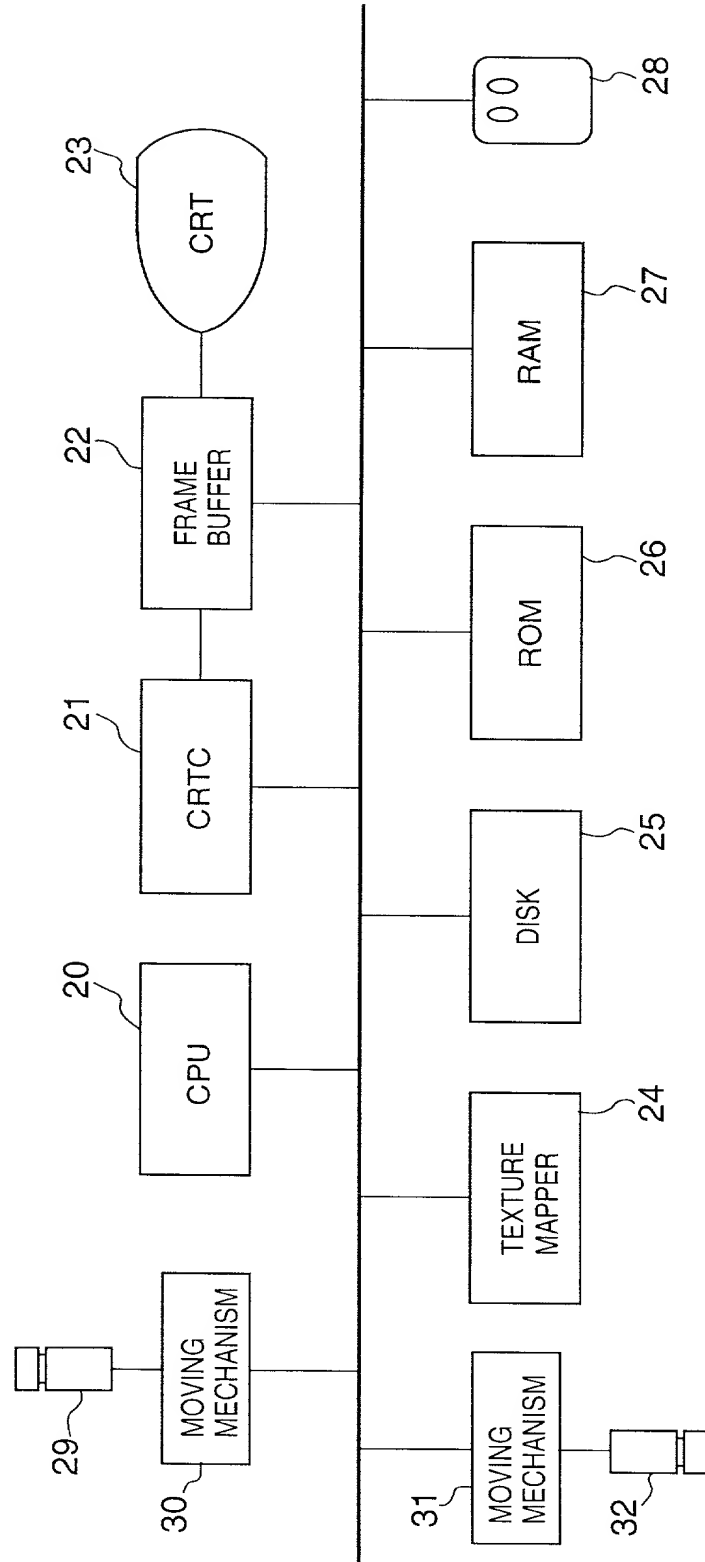
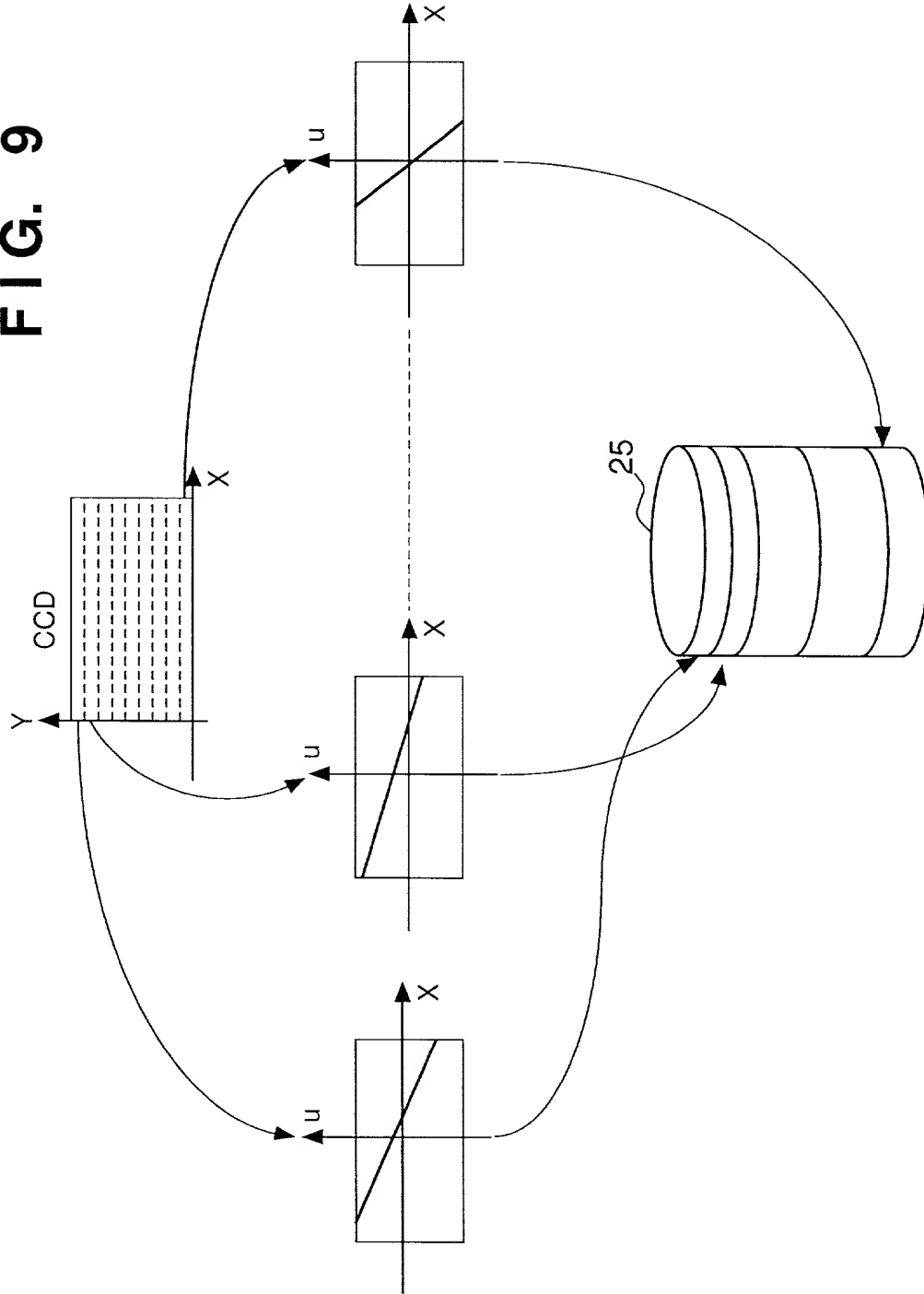


FIG. 9



**FIG. 10**

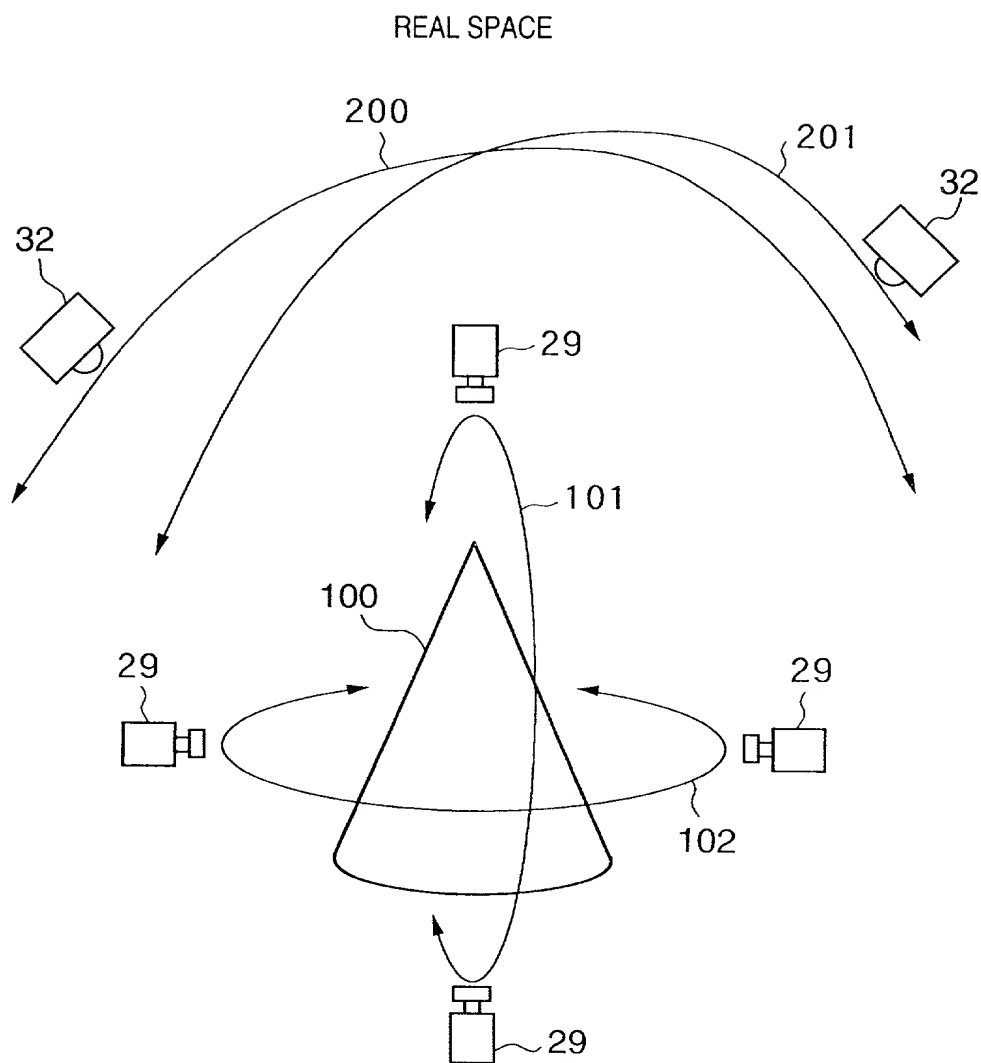


FIG. 11

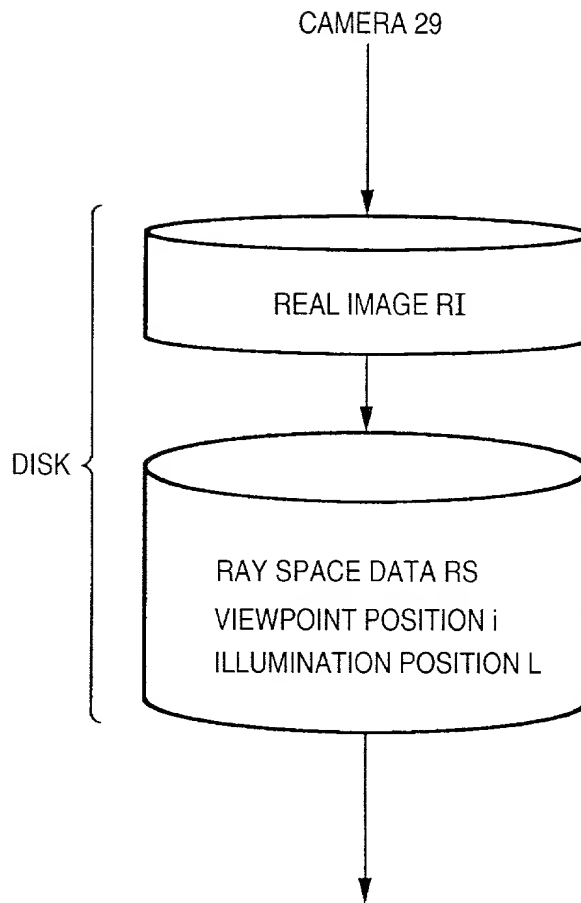
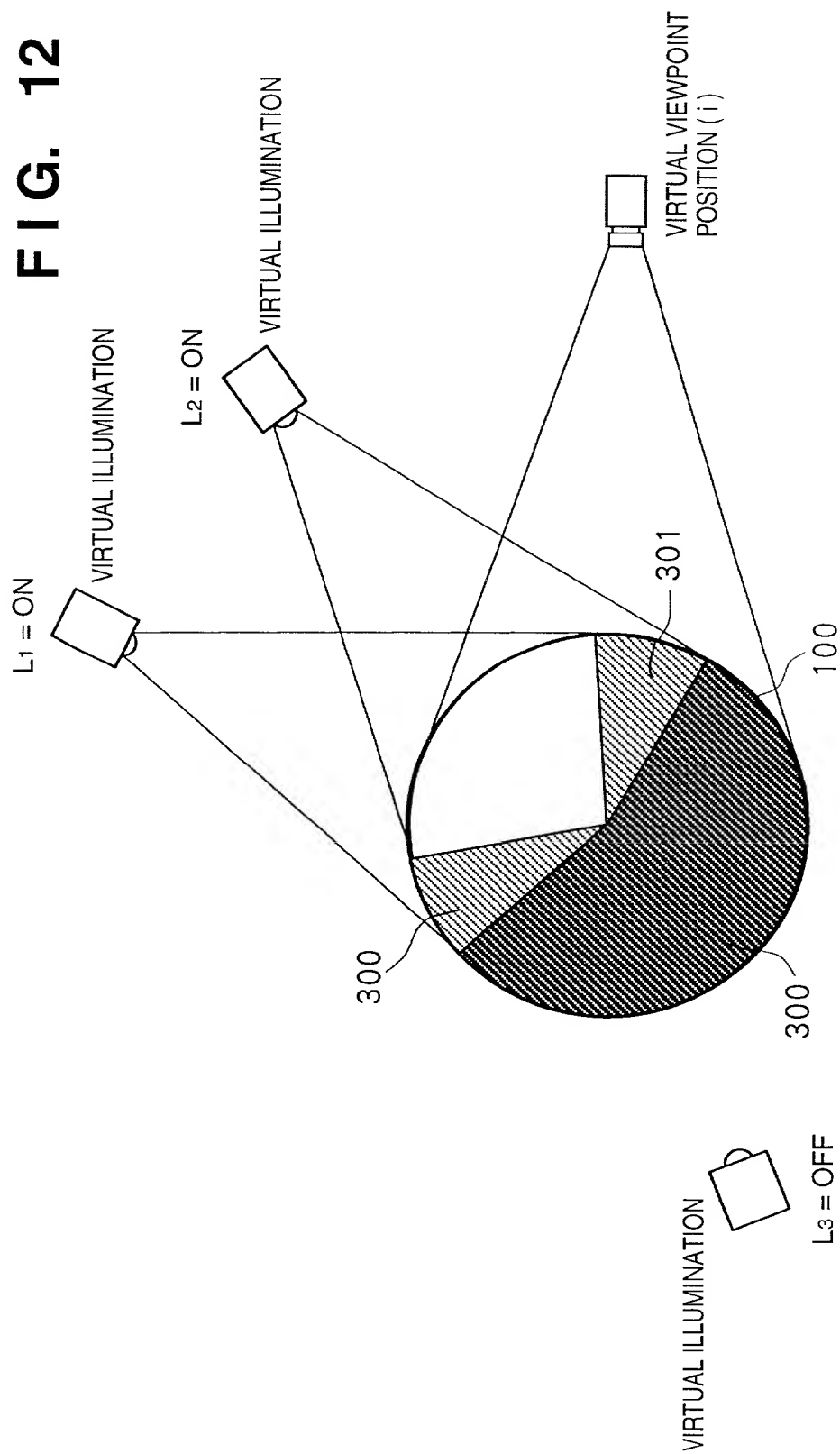
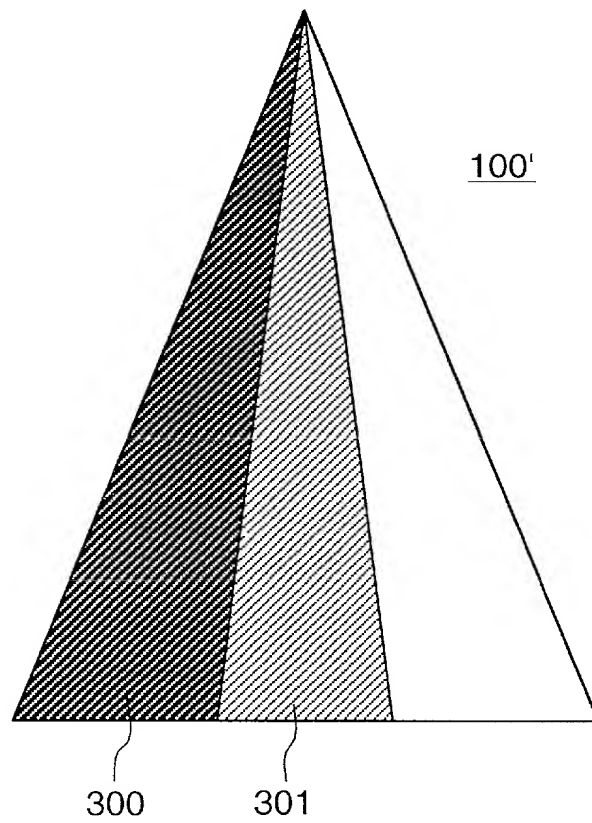




FIG. 12



**FIG. 13**



**FIG. 14**

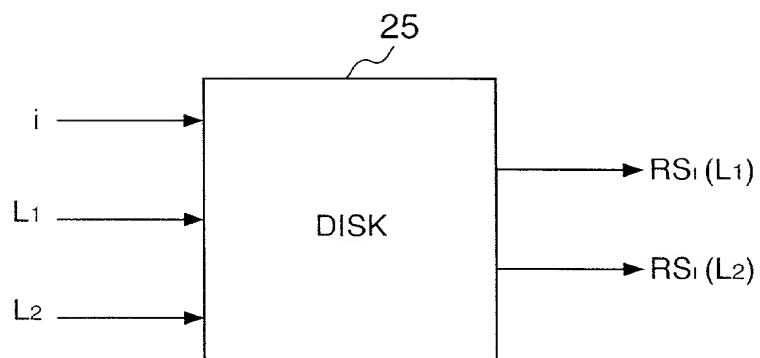


FIG. 15

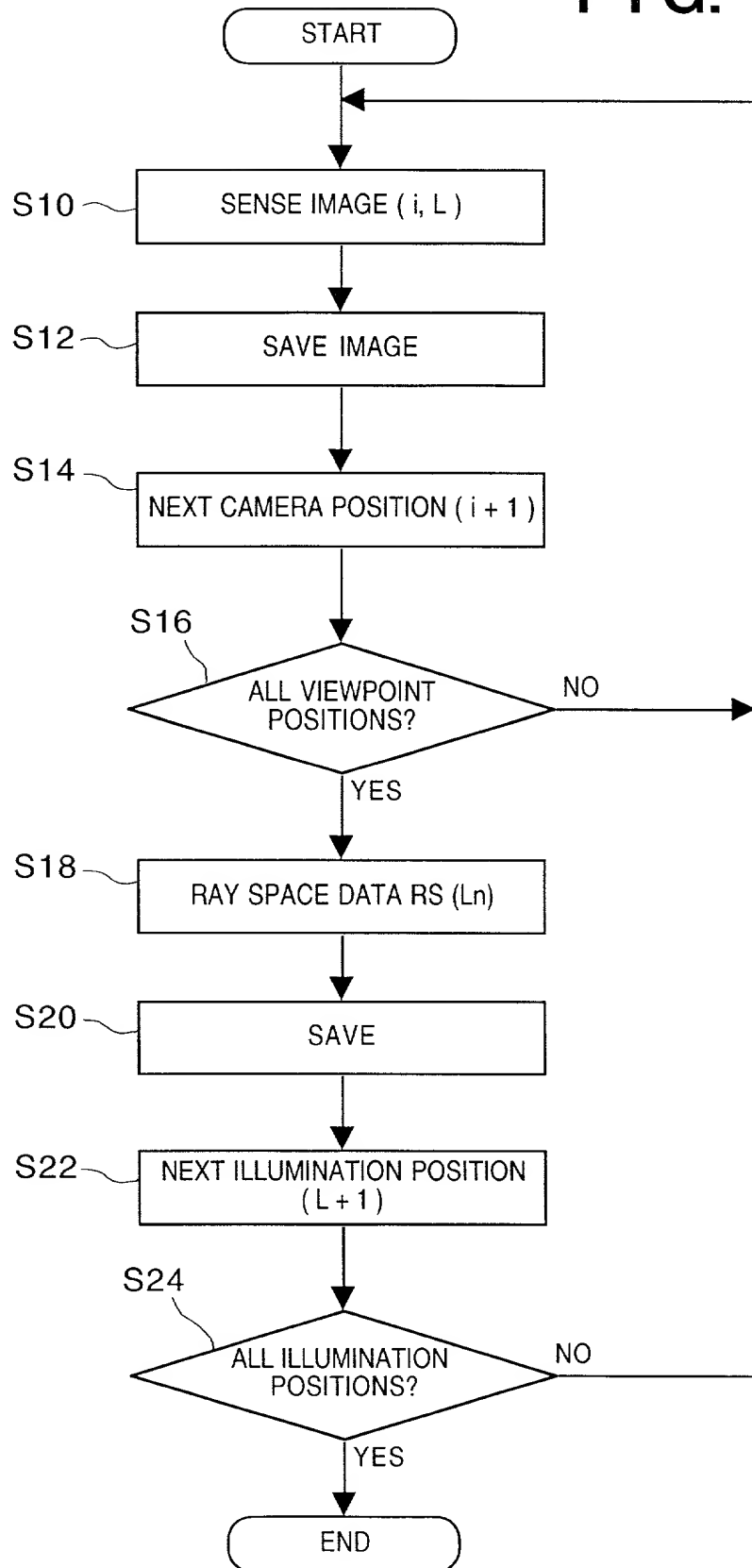
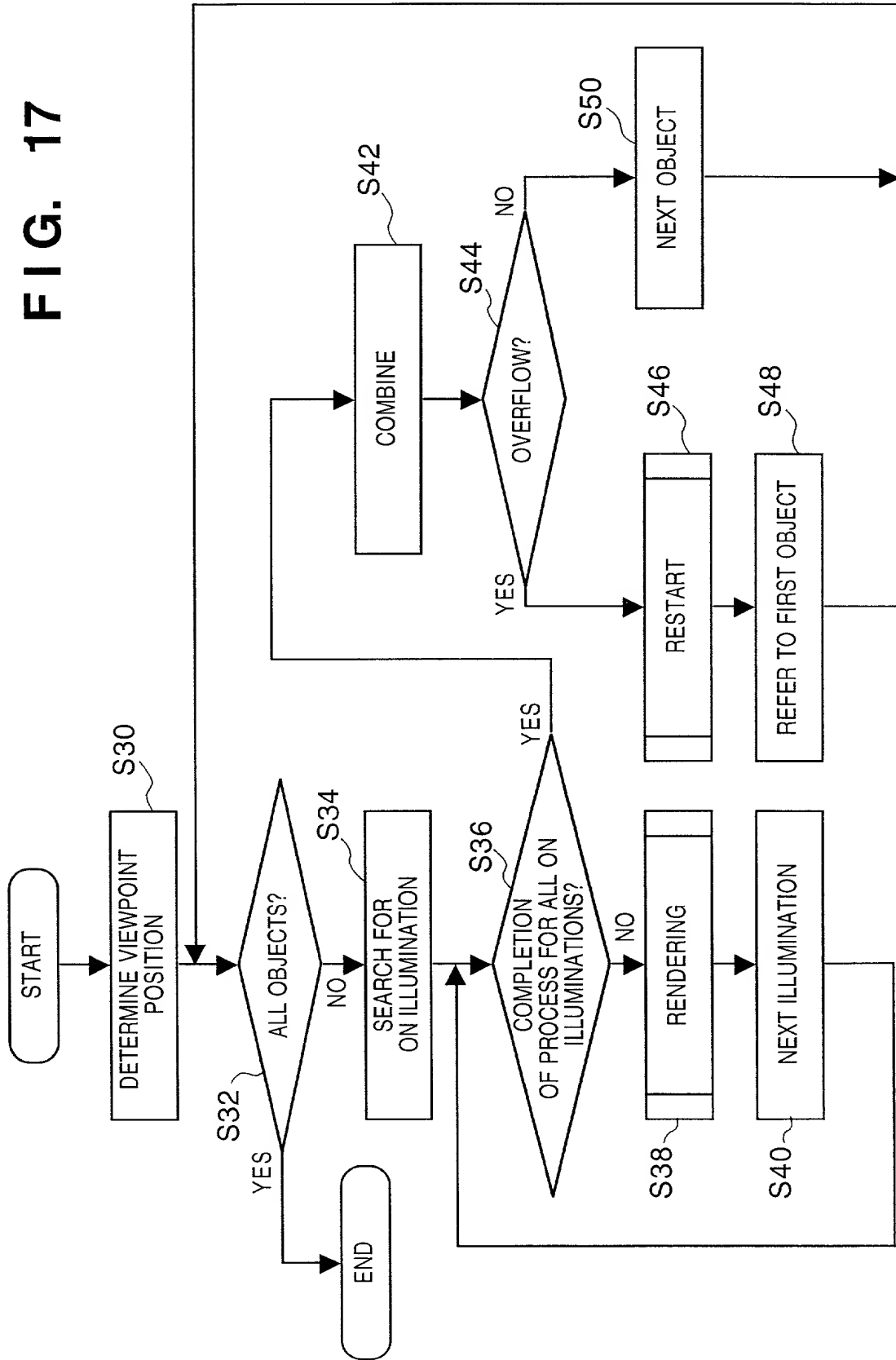
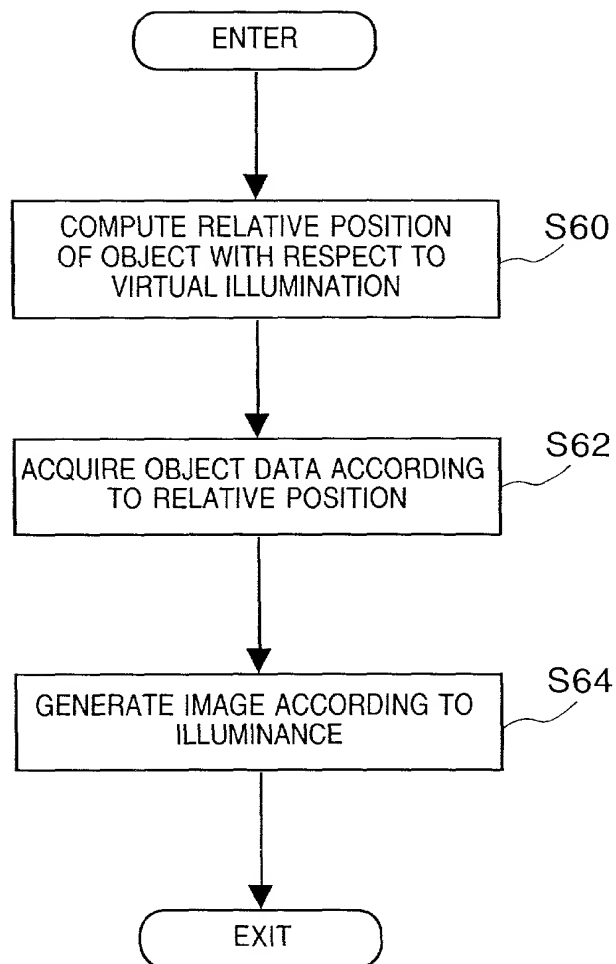


FIG. 16

ILLUMINATION ID	ON / OFF	POSITION	INTENSITY	COLOR
L1				
L2				
L3				
:				
:				

FIG. 17



**FIG. 18**

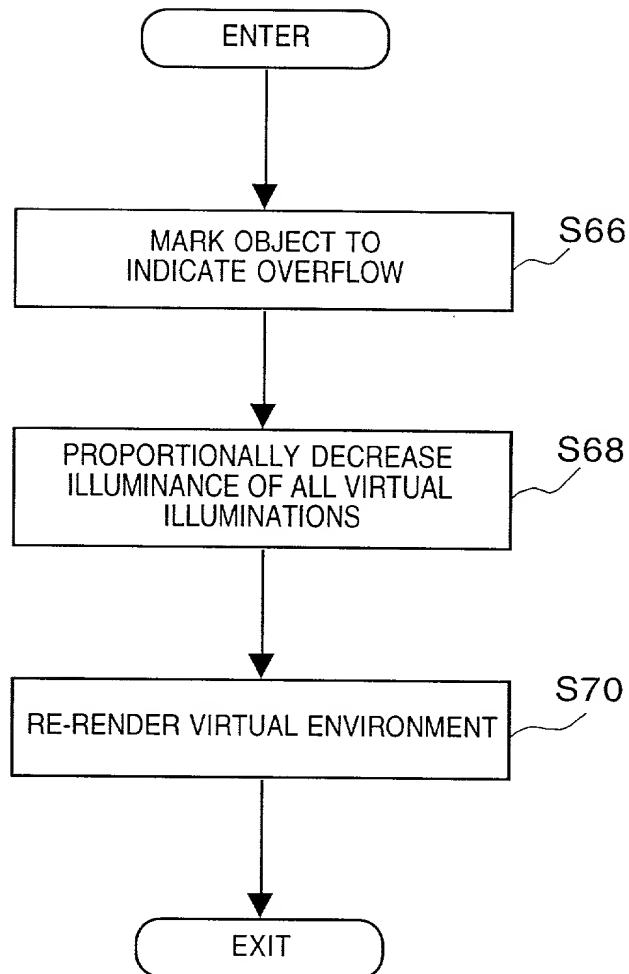
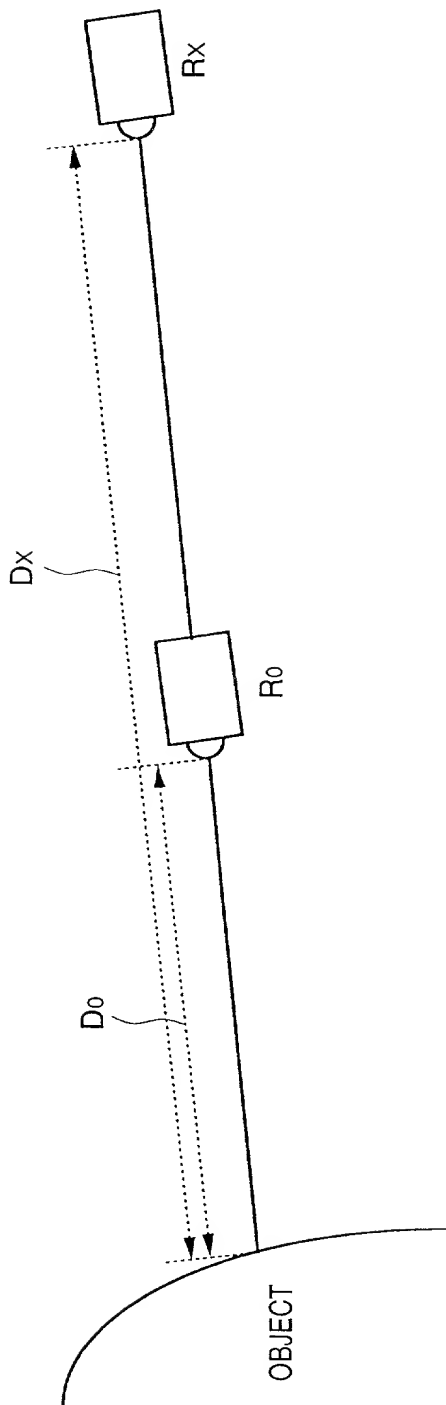
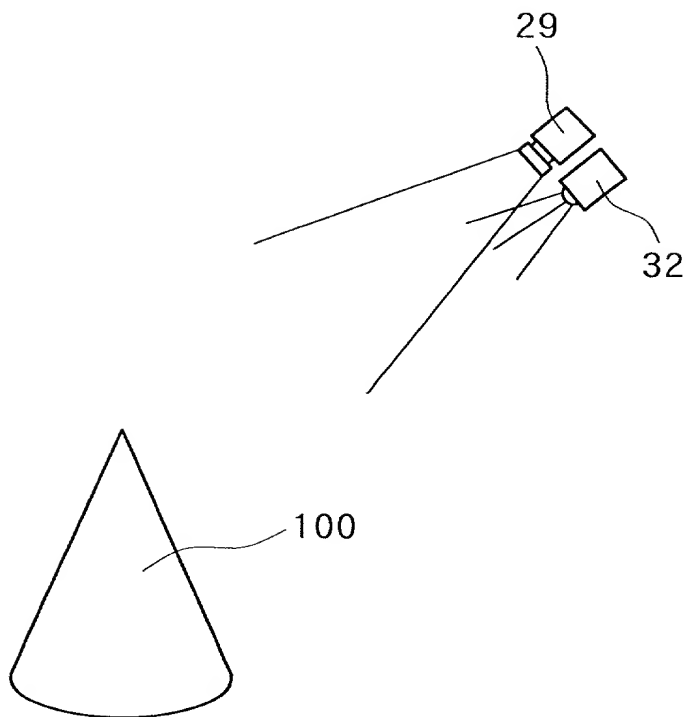
**FIG. 19**

FIG. 20

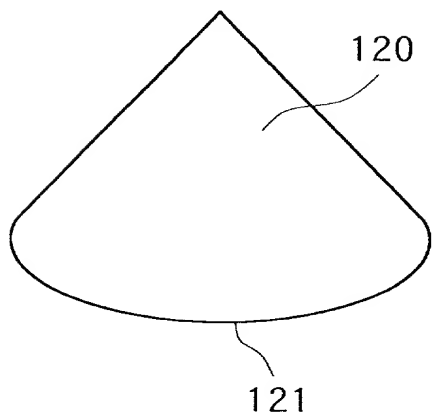




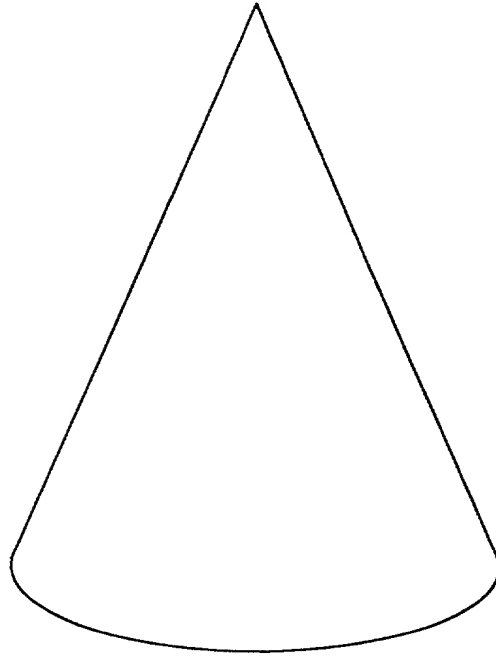
**FIG. 21**



**FIG. 22**



**FIG. 23**



**FIG. 24**

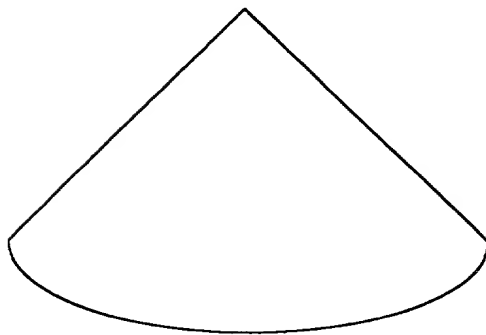


FIG. 25

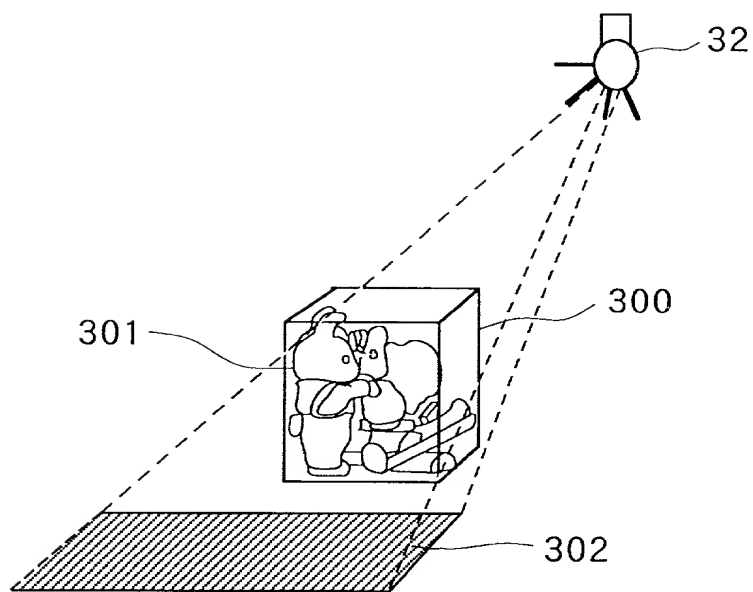
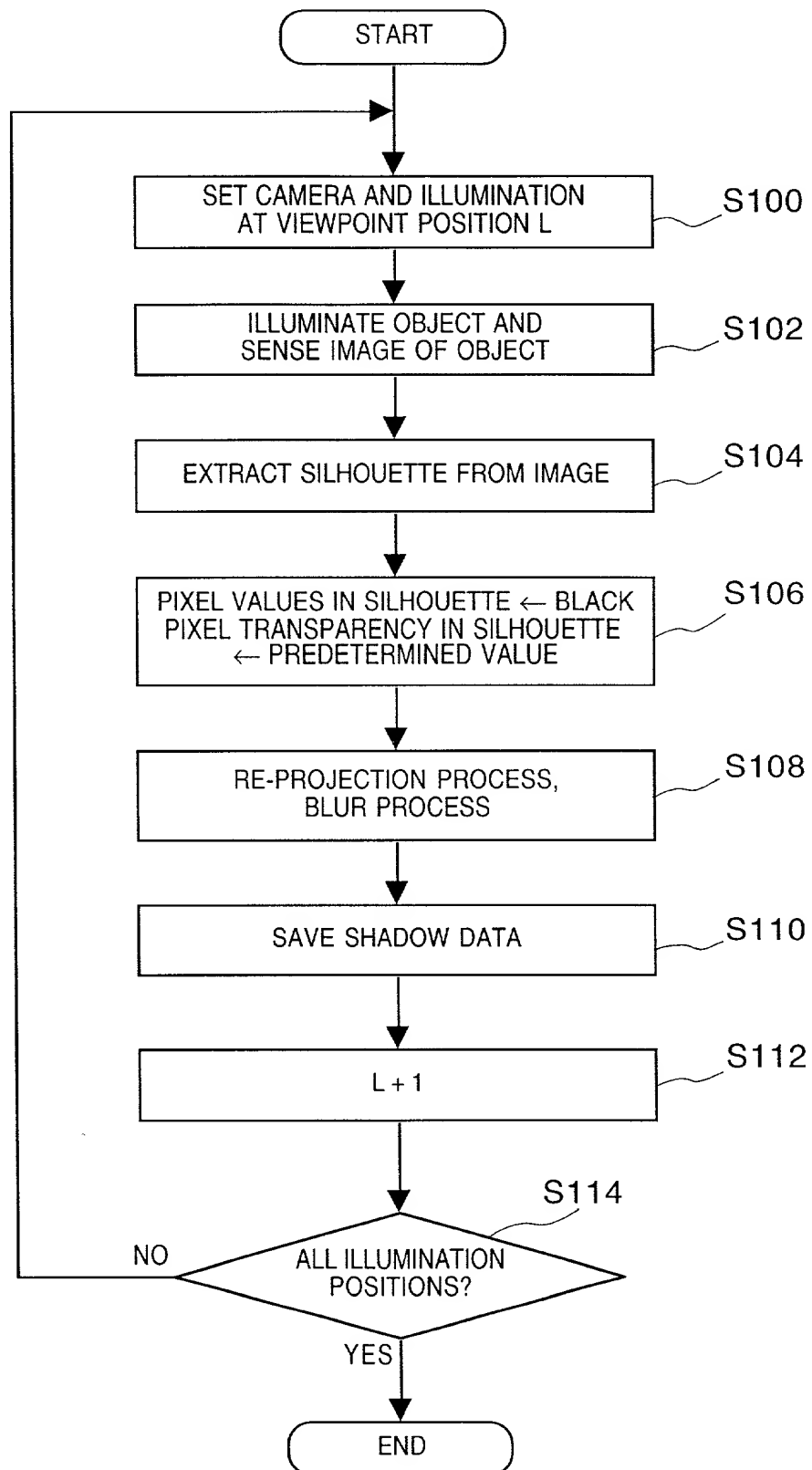


FIG. 26



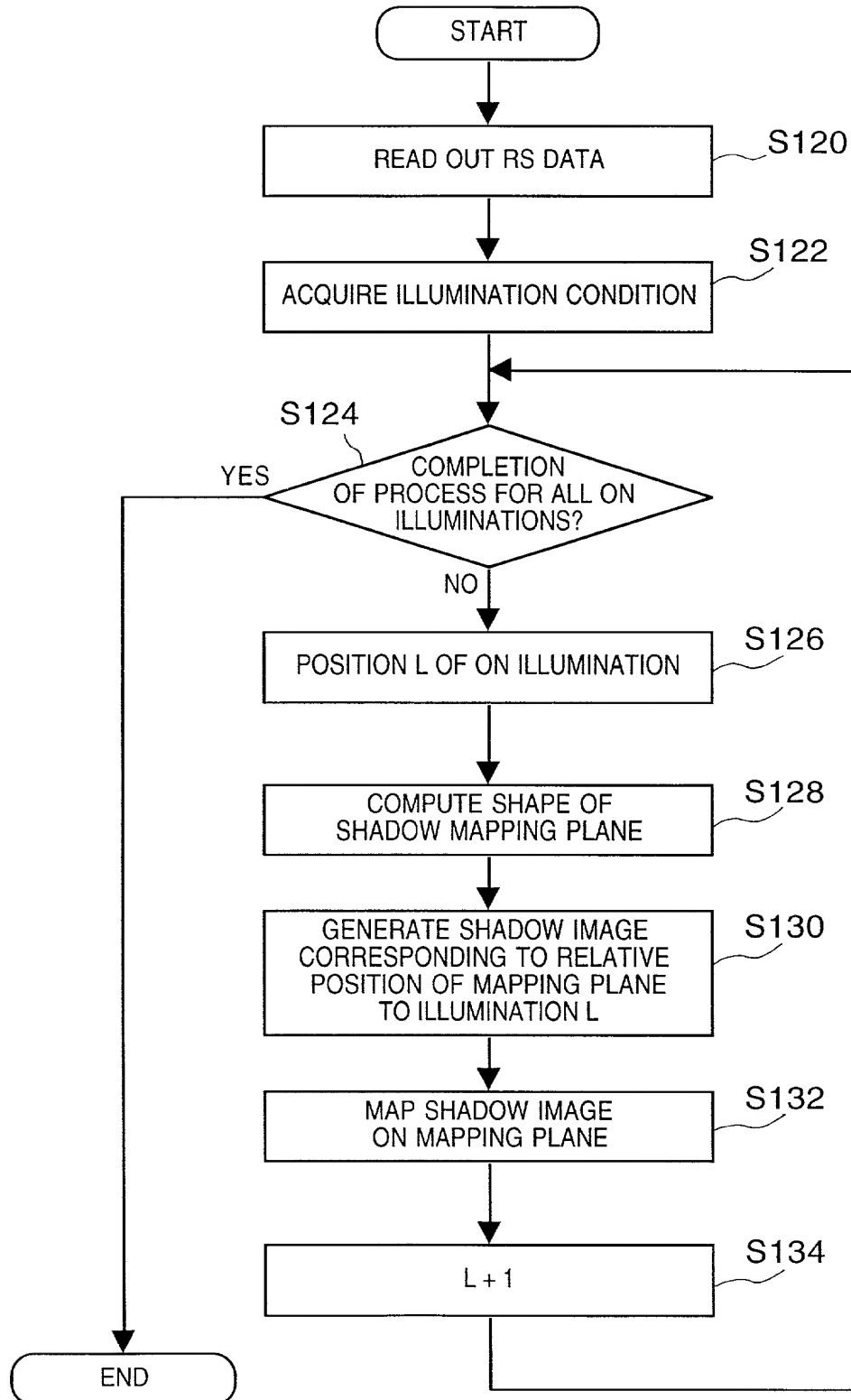
**FIG. 27**

FIG. 28

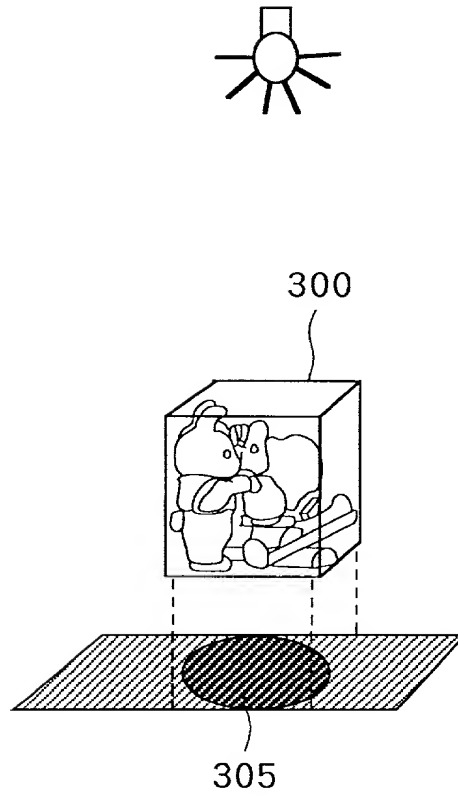
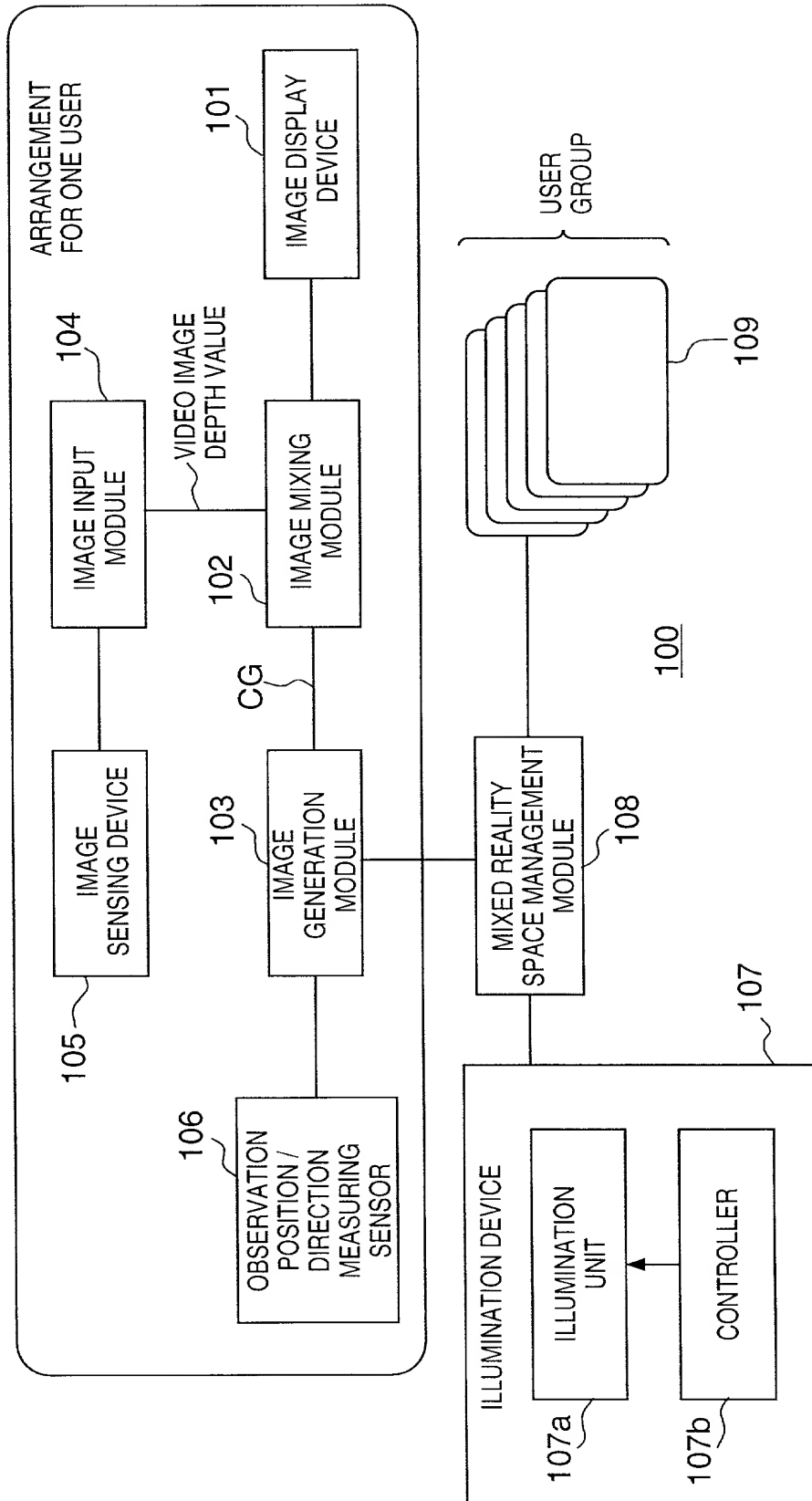


FIG. 29



**FIG. 30**

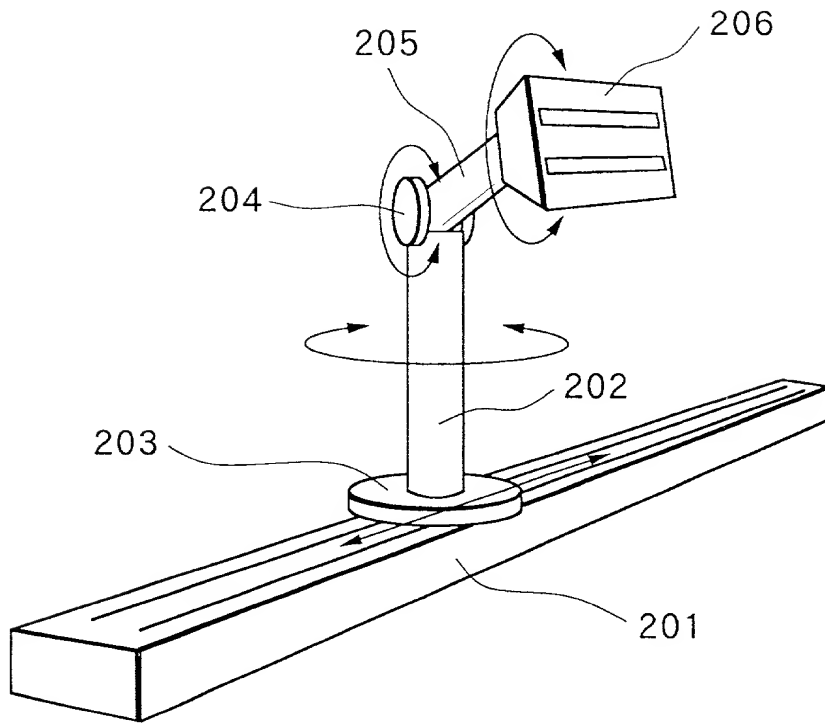




FIG. 31

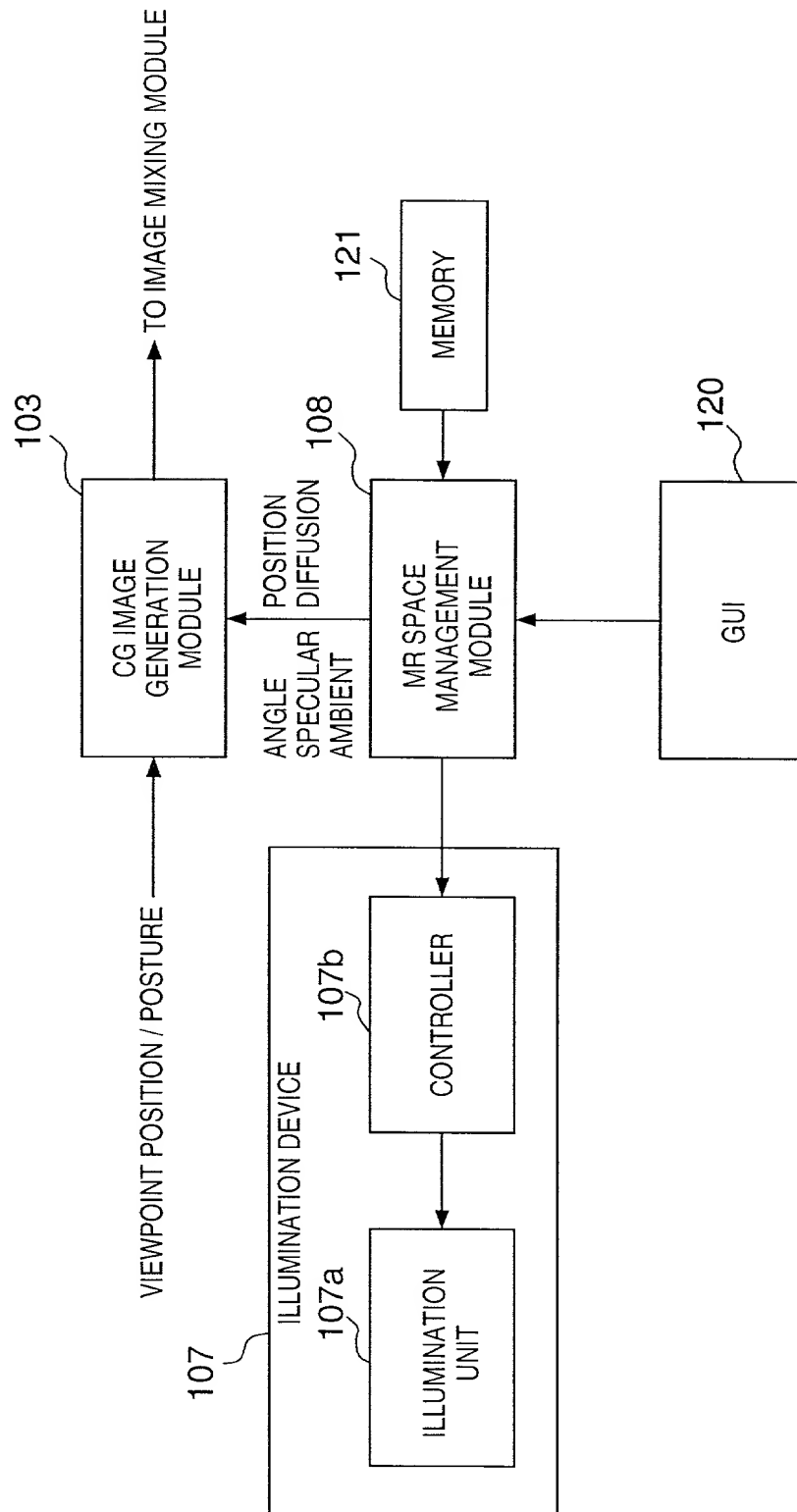


FIG. 32

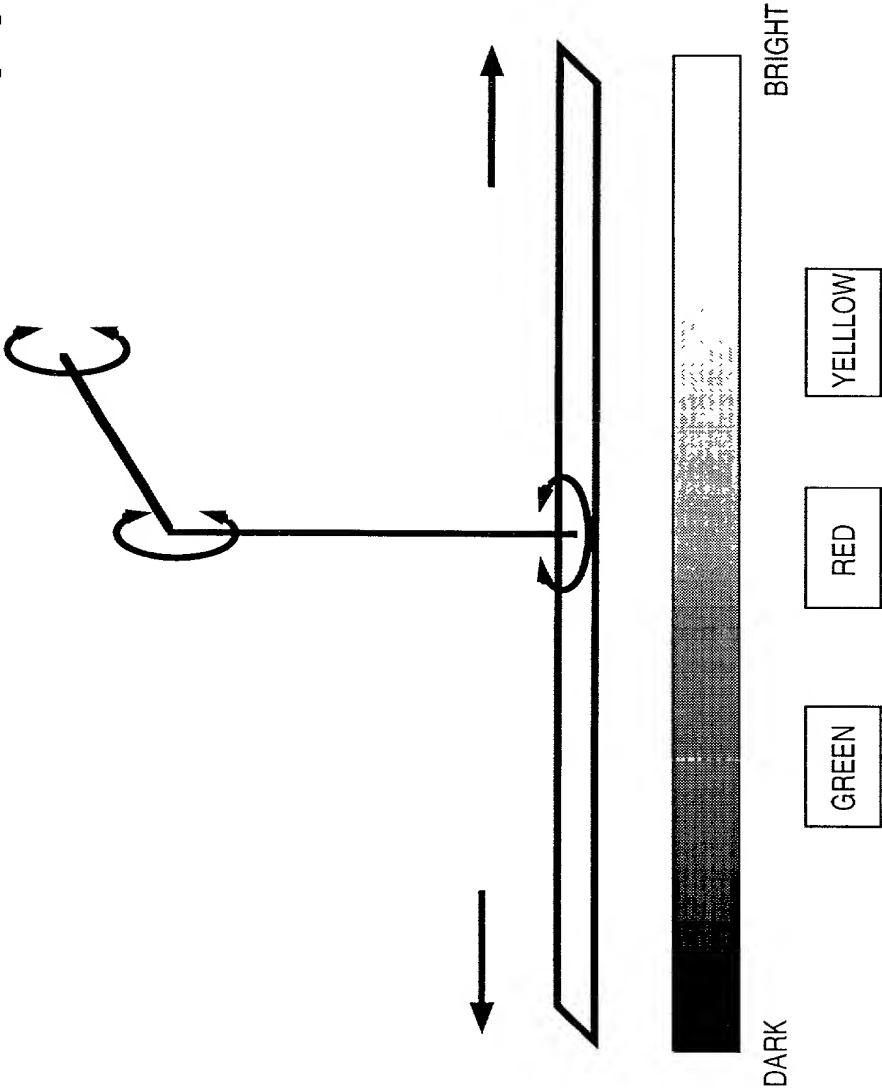


FIG. 33

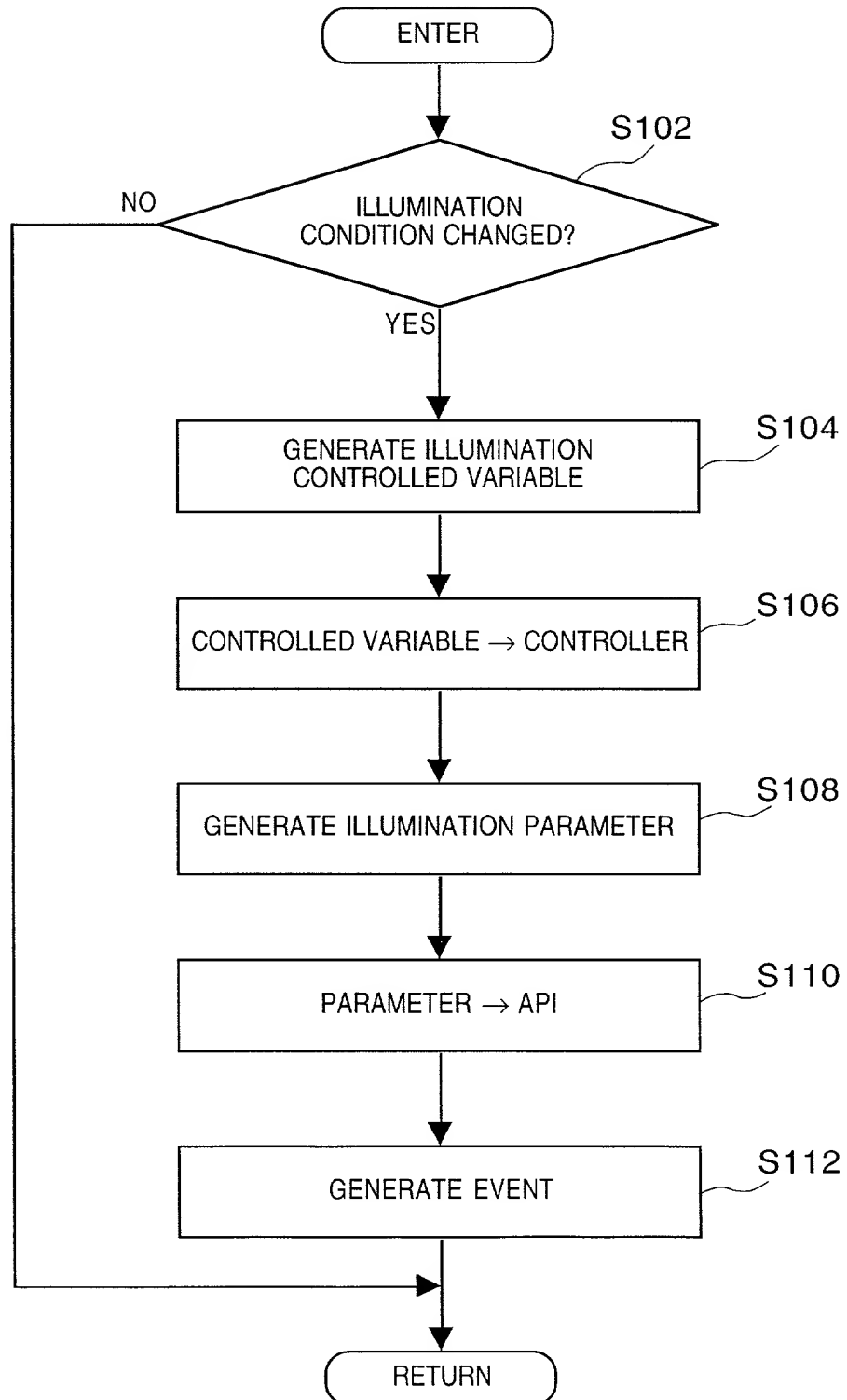


FIG. 34

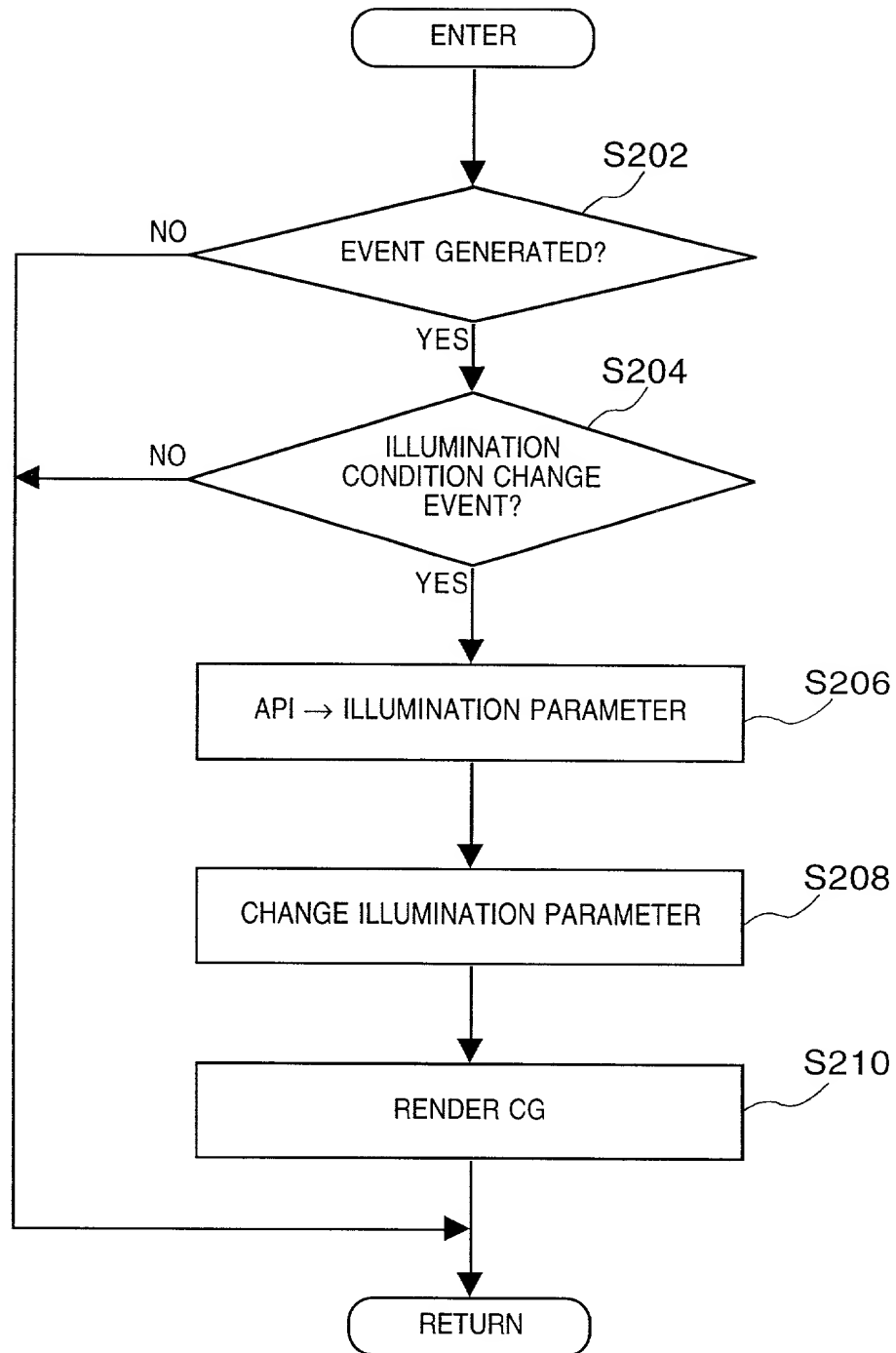


FIG. 35

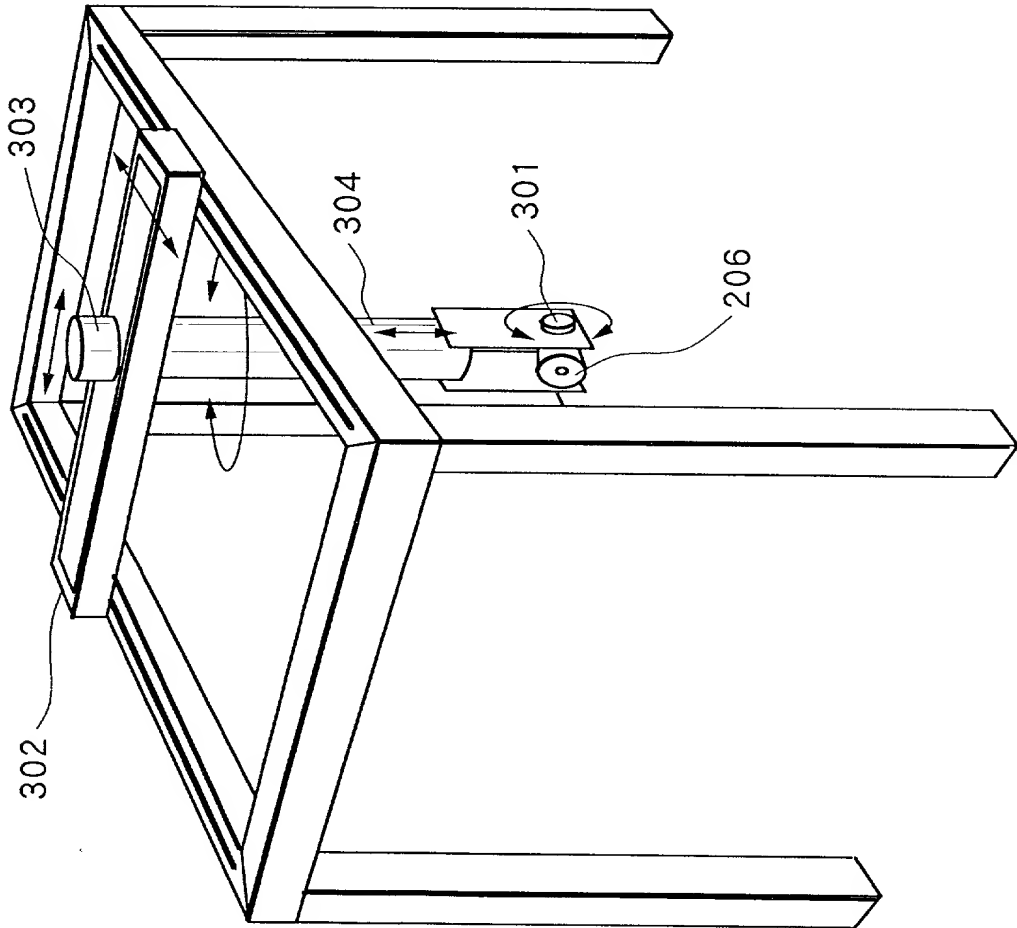


FIG. 36

ILLUMINATION POSITION ( n )	RAY SPACE DATA RS ( L <sub>n</sub> )
L <sub>1</sub>	RS ( L <sub>1</sub> )
L <sub>2</sub>	RS ( L <sub>2</sub> )
⋮	⋮
L <sub>k</sub>	RS ( L <sub>k</sub> )

FIG. 37

ILLUMINATION POSITION ( n )	SHADOW DATA SHADOW ( L <sub>n</sub> )
L <sub>1</sub>	SHADOW ( L <sub>1</sub> )
L <sub>2</sub>	SHADOW ( L <sub>2</sub> )
⋮	⋮
L <sub>k</sub>	SHADOW ( L <sub>k</sub> )

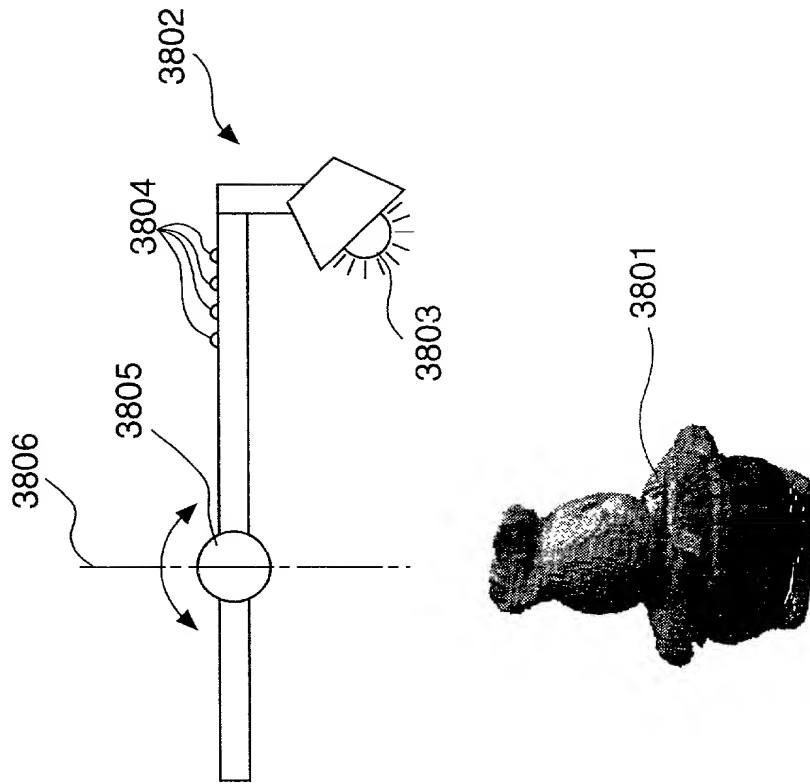
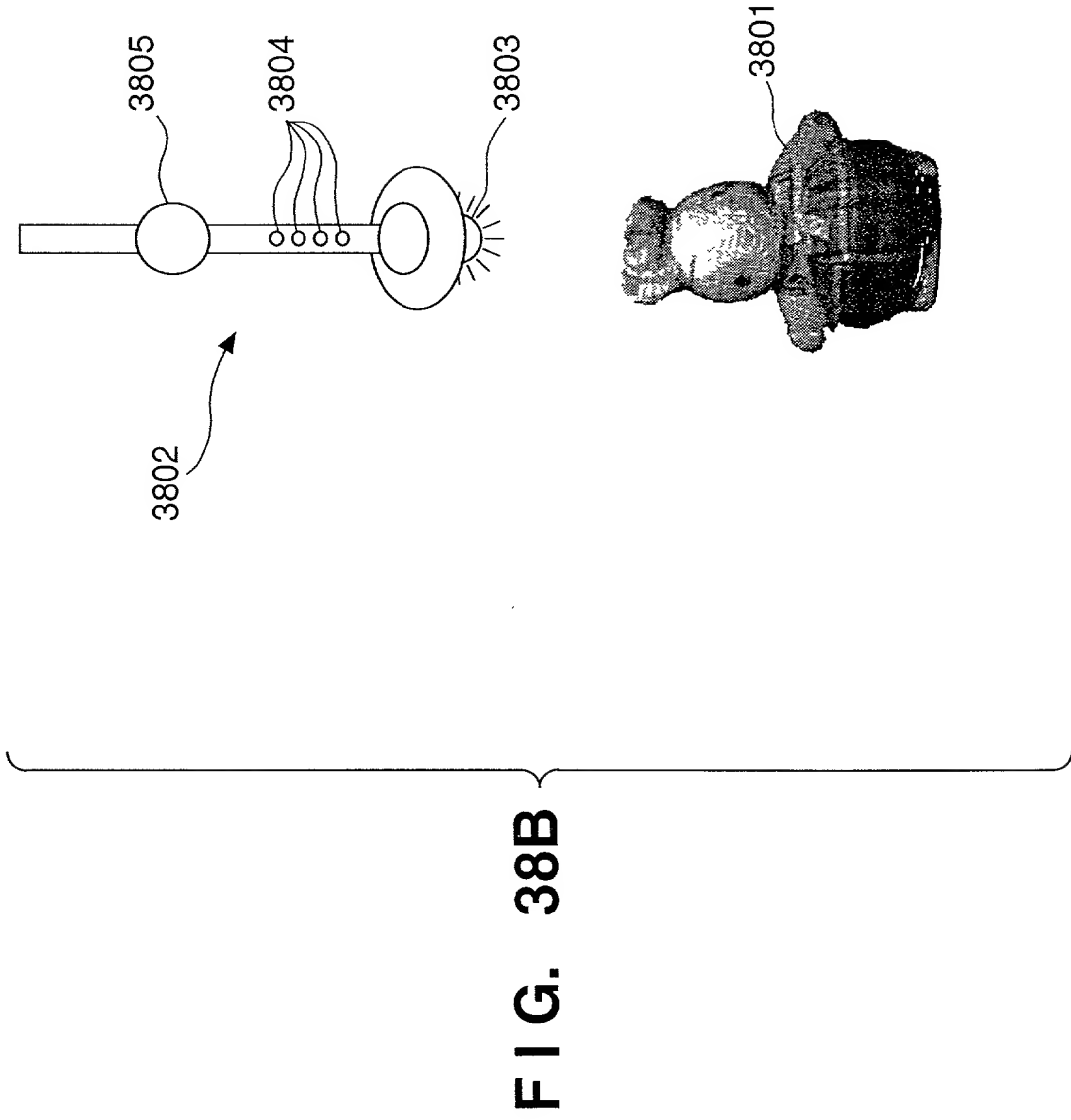


FIG. 38A





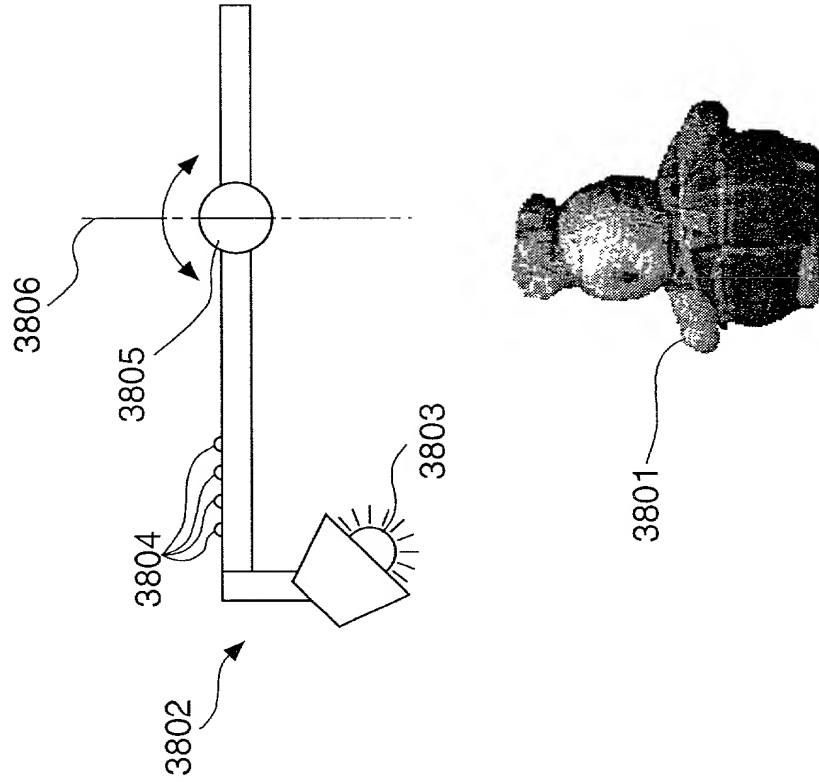


FIG. 38C

**COMBINED DECLARATION AND POWER OF ATTORNEY  
FOR PATENT APPLICATION**

(Page 1)

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

IMAGE PROCESSING METHOD AND APPARATUS

the specification of which [ X ] is attached hereto. [ ] was filed on \_\_\_\_\_

as United States Application No. or PCT International Application No. \_\_\_\_\_  
and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. §119(a)-(d) or §365(b), of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designates at least one country other than the United States, listed below and have also identified below any foreign application for patent or inventor's certificate, or PCT international application having a filing date before that of the application on which priority is claimed:

<u>Country</u>	<u>Application No.</u>	<u>Filed (Day/Mo./Yr.)</u>	<u>(Yes/No)</u> <u>Priority Claimed</u>
JAPAN	11-223958	06/08/1999	Yes
JAPAN	11-223959	06/08/1999	Yes
JAPAN	11-246770	31/08/1999	Yes

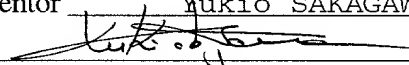
I hereby appoint the practitioners associated with the firm and customer number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith, and direct that all correspondence be addressed to the address associated with that Customer Number:

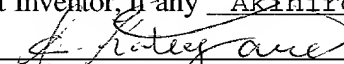
**FITZPATRICK, CELLA, HARPER & SCINTO**  
**Customer Number: 05514**

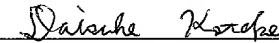
COMBINED DECLARATION AND POWER OF ATTORNEY  
FOR PATENT APPLICATION

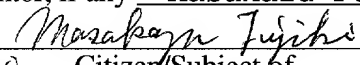
(Page 2)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Third Inventor's signature :   
Date February 17, 2000 Citizen/Subject of Japan  
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Full Name of Fifth Joint Inventor, if any \_\_\_\_\_  
Fifth Inventor's signature \_\_\_\_\_  
Date \_\_\_\_\_ Citizen/Subject of \_\_\_\_\_  
Residence \_\_\_\_\_  
Post Office Address \_\_\_\_\_